FEB 11 '52

Volume 21 DECEMBER, 1951 Number 4

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

« CONTENTS »

Lithology of the limestones at LeGrand, Iowa . . *Ralph W. Lawson* 189
Beach sand at Los Ojos de Agua de San Telmo, Michoacán, Mexico . . . . . *Fred M. Bullard and Richard A. Mills* 195
The occurrence and derivation of an augite-rich beach sand, Grenada, B.W.I. . . . . *H. S. Bennett and P. Martin-Kaye* 200
Pebbles from a pothole: a study in shape and roundness . . . . . *Dorothy Carroll* 205
SYMPOSIUM ON PALEOECOLOGY OF SHALE AND EVAPORITE DEPOSITION 213
Microfossils as environment indicators in marine shales . . . . . *Samuel P. Ellison, Jr.* 214
The depositional environment of red and green shales . . . . . *Ralph E. Grim* 226
The relationship of the biotic and lithic facies in Recent Gulf Coast Sedimentation . . . . . *Shepard W. Lowman* 233
REVIEWS
J. Harlan Johnson. An Introduction to the Study of Organic Limestones . . . . . *J. E. Lamar* 238
Page E. Truesdell and David J. Varnes. Chart Correlating Various Grain-Size Definitions . . . . . *Edwin B. Eckel* 238
ANNOUNCEMENTS
Annual Meeting, Society of Economic Paleontologists and Mineralogists 239
International Sedimentological Union 239
M. Theodore Kearney Foundation of Soil Science 240
INDEX 243

Journal of Sedimentary Petrology

J. L. HOUGH, EDITOR
University of Illinois
Urbana, Illinois

ASSOCIATE EDITORS

W. C. KRUMBEIN
Northwestern University
Evanston, Illinois

K. O. EMERY
University of Southern California
Los Angeles, California

HENRY B. MILNER
London, England

CLARENCE S. ROSS
Washington, D.C.

RALPH E. GRIM
University of Illinois
Urbana, Illinois

R. DANA RUSSELL
U. S. Navy Electronics Laboratory
University of California
San Diego, California

The *Journal of Sedimentary Petrology* is published by the Society of Economic Paleontologists and Mineralogists, a division of The American Association of Petroleum Geologists. Numbers are issued in March, June, September and December.

The subscription price of the *Journal of Sedimentary Petrology* is $5.00 per year prepaid to addresses in the United States.

Single numbers, $1.75 each ($1.35 to members).

Postage is charged extra for all other countries: 40 cents on annual subscriptions (total $5.40).

The *Journal* will furnish reprints at cost. Orders should accompany corrected galley proof.

Communications about the *Journal*, advertising, subscriptions, rates, memberships, change of address, and non-receipt of preceding number should be addressed to Society of Economic Paleontologists and Mineralogists, P.O. Box 979, Tulsa, Oklahoma. Claims for non-receipt of preceding numbers must be sent in within three months of the date of publication in order to be filled gratis.

Communications in regard to manuscripts and purely editorial matters should be addressed to J. L. Hough, Journal of Sedimentary Petrology, University of Illinois, Urbana, Illinois.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN
PRINTED IN THE U.S.A.

Volume 21 DECEMBER, 1951 Number 4

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

CONTENTS

Lithology of the limestones at LeGrand, Iowa.....*Ralph W. Lawson* 189
Beach sand at Los Ojos de Agua de San Telmo, Michoacán, Mexico..
.....*Fred M. Bullard and Richard A. Mills* 195
The occurrence and derivation of an augite-rich beach sand, Grenada, B.W.I.....*H. S. Bennett and P. Martin-Kaye* 200
Pebbles from a Pothole: a study in shape and roundness.....
.....*Dorothy Carroll* 205
SYMPOSIUM ON PALEOECOLOGY OF SHALE AND EVAPORITE DEPOSITION..... 213
Microfossils as environment indicators in marine shales.....
.....*Samuel P. Ellison, Jr.* 214
The depositional environment of red and green shales. *Ralph E. Grim* 226
The relationship of the biotic and lithic facies in Recent Gulf Coast Sedimentation.....*Shepard W. Lowman* 233
REVIEWS
J. Harlan Johnson. An Introduction to the Study of Organic Limestones.....*J. E. Lamar* 238
Page E. Truesdell and David J. Varnes. Chart Correlating Various Grain-Size Definitions.....*Edwin B. Eckel* 238
ANNOUNCEMENTS
Annual Meeting, Society of Economic Paleontologists and Mineralogists..... 239
International Sedimentological Union..... 239
M. Theodore Kearney Foundation of Soil Science..... 240
INDEX..... 243

NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal,* should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

Among papers to appear in forthcoming issues of the *Journal* are the following:

Symposium on Microbiology in Relation to the Geologic Accumulation of Organic Complexes:

Mechanism of cellulose degradation by chemical and biological agents. By Ralph G. H. Siu.

Degradation of plant remains in organic sediments. By Elso S. Barghoorn.

Depositional environment of source materials forming organic sediments. By Irving A. Breger.

Part played by bacteria in petroleum production. By Claude E. ZoBell.

How important was decay in the origin of Paleozoic coal? By James M. Schopf.

Microbiology of cellulose, hemicellulose, pectins and gums. By A. C. Thaysen.

Other papers:

A comparison of tissue preservation in coalified and silicified logs. By Aureal T. Cross.

Adaptation of the piston coring device to shallow water sampling. By Maxwell Silverman and Richard C. Whaley.

Deep ripple marks in the sea. By Henry W. Menard.

Possible utilization of electrophoretic phenomenon for separation of fine sediments into grades. By George Tchilligarian.

Clastic quartz particles as indices of provenance. By John Bokman.

Discussion:

Loess, an eolian product: correction and a reply to the remarks of F. F. F. E. van Rummelen. By D. J. Doeglas.

Reply to the remarks of N. M. Shukri on "Beach sands of the Mediterranean coast of Egypt." By M. E. Hilmy.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 189–194
FIG. 1, DECEMBER, 1951

LITHOLOGY OF THE LIMESTONES AT LEGRAND, IOWA

RALPH W. LAWSON
University of Wisconsin, Madison, Wisconsin

ABSTRACT

The results of studies of thin-sections, insoluble residues, and dolomite-calcite ratios of the limestones at LeGrand, Iowa, are presented graphically. Though the section studied at LeGrand consists entirely of limestone and dolomite, with associated cherts, there seems to be a five-fold cyclic repetition of beds.

INTRODUCTION

The limestone beds at LeGrand, Marshall County, Iowa, are famous for the abundance of excellently preserved crinoids found in them. These limestones, locally termed the "LeGrand beds," comprise parts of two formations of Kinderhookian age. The basal 18 feet is the Chapin oolite, and the remainder of the section is a part of the Hampton formation. A number of workers have decribed and listed the fossils from these beds. Laudon (1931) zoned the beds on the basis of faunal assemblages and described the general lithologic character of the paleontological zones.

The purpose of this investigation was to make a detailed lithologic study of the "LeGrand beds." The macrolithology of each bed was described and samples were taken about one foot apart from top to bottom of the 70 foot quarry face. Chert horizons were accurately located in the section by measurement, but the chert itself was not studied.

Figure 1 is a graphical representation of most of the pertinent data and serves as a basis for the discussion below. Complete descriptions of the microlithologies of individual beds may be found in the original thesis, on file in the Iowa State College library.

ACKNOWLEDGMENTS

The writer is indebted to C. J. Roy, Iowa State College, for his suggestions and encouragement; to G. H. Otto, Illinois Institute of Technology, for his advice on staining techniques; to C. W. Carson, Concrete Materials and Construction Co., Cedar Rapids, Iowa, for cooperation in the work done in company quarries; to Fred H. Dorheim, Cedar Rapids, Iowa, for transportation and field assistance; to F. S. Schultz and J. H. Jonte, Iowa State College, and to V. L. Culbertson, Shell Oil Co., for assisting with the chemical analyses.

PROCEDURE

The laboratory work was threefold; the study of thin-sections, the analysis of insoluble residues, and the determination of calcite-dolomite ratios. The vertical distribution of samples used for each of these studies has been plotted against the geologic column in figure 1.

Thin-sections

The thin-sections are thought to be representative of the various lithologic types. Data obtained from these sections include texture, relative abundance of calcite types, and the relationship between various minerals. An improved Wentworth recording micrometer was used to determine the relative abundance of the several constituents.

Several types of calcite are recognized in thin-section. Fossil, clastic, and recrystallized calcite have been differentiated as distinct types, and have been plotted as per cent total calcite against the geologic column in figure 1. The calcite of ooliths, which may be a type in itself, has

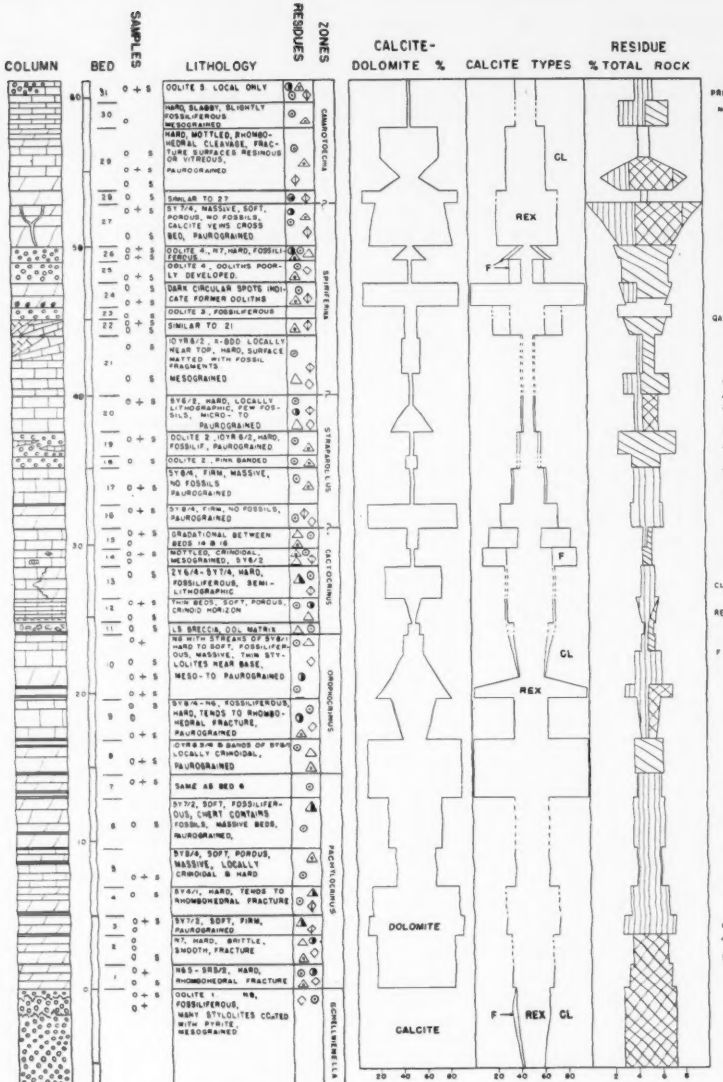


FIG. 1.—LeGrand Section and Microfacies.

been plotted with the clastic calcite. The nuclei of ooliths were recorded as fossil or recrystallized calcite if recognizable as such. A possible fifth type of calcite is found as a secondary growth about fossil fragments. It is clean homogeneous calcite in crystallographic continuity with the fossil calcite. This type is similar to the recrystallized calcite and it has been recorded with the recrystallized calcite for the purpose of plotting percentages.

"Clastic calcite," as used here, refers to small dirty anhedral grains and does not, necessarily, indicate the origin of such calcite (Alling, 1946). The term is probably a misnomer, and is used as a type name for lack of something more appropriate.

Residues

The insoluble residues were studied under a binocular microscope, and described in the terminology suggested by H. A. Ireland and others (1947). The quantity of residue has been plotted as per cent total rock in figure 1. The shading represents the principal non-argillaceous residue of each bed. The term "argillaceous," as used here, refers to all residue less than about 0.018 mm in diameter. In the Alling grade scale 0.018 mm is the boundary between fine silt and very fine silt, so that very fine silt has been included in the argillaceous fraction. The argillaceous residue has not been subdivided further or identified in this study. The term "arenaceous" is used to denote land-derived material greater than 0.018 mm in diameter. Most of the important residue constituents are represented qualitatively in the column headed "Residues." The symbols employed in this column are, in part, after Wengerd (1948).

Calcite-Dolomite Ratios

The dolomite and calcite content of each bed is plotted as per cent total carbonate in figure 1. The dolomite content was determined by one of Lemberg's staining techniques, modified by the author to give rapid quantitative results (Lawson, 1950).

The faunal zones delimited by Laudon and brief remarks on the macrolithology are also shown in figure 1. The letters and numbers listed under "Lithology" refer to the color of rock determined from the Rock-Color Chart (National Research Council, 1948). The textural terms are those propoesd by DeFord (1946), for use with the Alling scale.

DISCUSSION

The principal points of interest in the lithology of the "LeGrand beds" are (1) dolomite content, (2) chert, (3) calcite types, (4) textures, (5) insoluble residues, and (6) oolite beds. Although these are not entirely independent of each other they will be discussed separately.

Dolomite

A discussion of this subject is always difficult because of the confused terminology. As often suggested, it is certainly desirable to find a name other than "dolomite" for a rock containing more than 50 per cent of the mineral dolomite.

In the "LeGrand beds" the mineral dolomite occurs as individual grains disseminated through a matrix of calcite. Here, the mineral dolomite may comprise any fraction of the carbonate component from zero to about 85 per cent. No bed above oolite I (see fig. 1) has a carbonate component consisting entirely of dolomite, nor entirely of calcite. The literature describes the 25 to 30 feet of rock just above oolite I as dolomite, and the remainder of the "LeGrand beds" as limestone. This is simply not true. Although the 25 to 30 feet of rock just above oolite I generally contain more dolomite than calcite, some individual beds in this interval are predominantly calcite. Moreover, several beds in the upper 30 feet contain much more dolomite than calcite.

Within a given bed the mineral dolomite is usually distributed through the calcite matrix with considerable uniformity. An occasional exception is the concentration of dolomite grains in irregular masses in a bed that is otherwise

a nearly pure calcite limestone. Some isolated masses of dolomite-free calcite are found in beds that are predominantly dolomite. There is no evidence of dolomitization being controlled by joints or veins.

Chert

In figure 1 the indicated chert layers actually represent horizons of chert nodules or lenses. The nodules occur both as isolated spheroids or irregular masses interfingering with the limestone, and as groups of coalescent lenticular nodules. The chert lenses parallel the stratification and are usually discontinuous laterally. One or two of these lenses may be continuous over a considerable area, as they consistently occur at the same horizon in several exposures, and they do not terminate in any of these exposures.

The occurrence of chert bodies at definite horizons is confined to the 33 feet of the section immediately above oolite I. This interval also contains the bulk of the beds that have a high dolomite content. In this interval, where a lens of chert is missing, the limestone of the corresponding zone often has a cherty residue. Although chert lenses and nodules are generally absent from the upper part of the section, the residues in several of the higher beds are predominantly chert.

Calcite Types

There is some concordance of maxima between dolomite content and recrystallized calcite content, but it should be remembered that the total calcite content is low in such rock. A lower percentage of recrystallized calcite in other beds may actually represent a greater degree of recrystallization.

Bed 20, which is largely lithographic, has the highest content of clastic calcite and the lowest content of recrystallized calcite. Fossil calcite, in general, is rare or absent in beds containing more than about 20 per cent dolomite.

Texture

In figure 1 the rock textures are briefly and inadequately described by single terms under "Lithology." The terms are those of DeFord (1946) and, like most carbonate rock textural terms in vogue today, fail completely to convey the complexity of textures observed in such rocks. The texture of the LeGrand carbonate rocks cannot be defined by a single statistical measure or by one term alone. The subject of textures and their classification will be discussed in detail in a later paper.

Residues

Quantity of residue does not seem to be significant in the LeGrand rocks, and in no one bed does the insoluble material constitute more than 10 per cent of the rock. Though it is not obvious from figure 1, the total quantity of residue in the rocks is largely a function of the argillaceous content. In general, fluctuations in the amount of coarser residue are much smaller than fluctuations in argillaceous residue.

The components of the insoluble residues of particular interest are variscite (?), glauconite, and pyrite. The mineral called variscite in this study occurs as finely aggregated lath-like crystals, transparent, green to nearly colorless. Usually anisotropic (orthorhombic ?), some grains appear to be isotropic. The index of refraction is about 1.59. The mineral is highly birefringent and contains opaque inclusions. Variscite (?), an aluminum phosphate, is never abundant in the "LeGrand beds" and it seems to have a random distribution throughout the section.

Glauconite is most abundant near the tops of oolite beds or in beds immediately above oolites. Its occurrence just above bed 11 is important as this bed is a limestone conglomerate with an oolitic matrix. The occurrence of glauconite in beds 9 and 10 does not seem to be related to an oolite. Though the author was unable to find any evidence that bed 8 had ever been oolitic, older reports indicated an oolite at about this horizon in other localities. Glauconite is being formed today in brackish waters on coastal plains, and a transgression of the Mississippian sea

may have winnowed this mineral out of similar deposits and incorporated it in the limestones.

Pyrite (or limonite pseudomorphs after pyrite) is distributed throughout the section, but, in general, it is most abundant in oolites or beds immediately above oolites, as is glauconite.

Oolitic Beds

Five times during the time interval represented by the rocks at LeGrand, conditions favorable for the formation of oolites were present in this area. These five times are represented by oolite I; bed 11, which has an oolitic matrix; oolite II; oolites III and IV, which were formerly one continuous oolite; and oolite V.

Oolites III and IV, in the outcrop, appear to be two distinct oolites separated by a dark blue-gray massive dolomite. Close inspection of this dolomite reveals many small circular areas of a darker color. In thin-section it is obvious that these dark circular spots were once oolites that have been recrystallized and then dolomitized. A thin film of pyrite has preserved the outline of many of the individual ooliths.

Beds associated with three of the oolites indicate contemporaneous erosion which suggests shallow water, or at least conditions other than normal marine. Below oolite I is an erosion surface and conglomerate in the English River formation. Bed 11 is an intraformational conglomerate with an oolitic matrix and the beds subjacent to oolites III and IV are cross-laminated and fragmental.

The conditions for the formation of marine oolites are not well known, and may be varied. The weight of evidence, both in the literature and at LeGrand, favors a near shore, or shallow water, environment for their formation. Every oolite in the section is followed by more normal marine carbonate rocks, which are well bedded and more or less massive. The change from oolite formation to deposition of a more normal marine rock is not always as abrupt as the sharpness of the contact would indicate. A careful study of the ooliths in oolite I shows that ooliths near the upper contact of this bed are smaller and geometrically less regular in outline than those lower in the bed. Also, the ooliths make up less of the total rock near the top than they do lower in the bed, where they are more closely packed. These differences indicate a gradual change, from conditions favorable to the growth of ooliths to other conditions.

The oolitic rocks contain brachiopods and bryozoans most abundantly, whereas the more normal marine rocks at LeGrand contain echinoderms most abundantly. This suggests a change in ecological conditions, and may partly account for the abundance of pyrite at certain horizons. The occurrence of pyrite probably is due to the decomposition of organic matter in waters containing iron. Shallow agitated waters would be most favorable for the decomposition of organic matter, and for the formation of ooliths.

SUMMARY

In the past few years there has been an increasing awareness of cycles in sedimentation, but all of the cyclic sedimentation dealt with in the literature involves alternation of clastic, or of clastic and non-clastic, rocks. At LeGrand there is a strong suggestion of cyclic sedimentation within an exclusively carbonate sequence. Obviously, there was a recurrence of oolite deposition. Generally, beds immediately underlying oolites are cross-laminated, or fragmental, or conglomeratic. Beds immediately overlying oolites appear to be of a more normal marine nature. Glauconite and pyrite are most abundant in oolites or in immediately overlying beds.

The oscillations between various depositional environments that are suggested by these variations in lithology may be described as follows:

1. Agitation of water, associated perhaps with relative lowering of sea level, resulting in fragmentation of the hard

parts of organisms, notably crinoids and brachiopods; breaking up of semi-indurated sediments and formation of conglomerates; and locally some erosion.

2. Continued agitation and development of conditions peculiarly favorable to the formation of ooliths and the deposition of an oolite. Glauconite formed in this environment or was winnowed from adjacent areas.

3. Decrease in agitation, associated perhaps with deepening of the water in this area, with the transition from oolite deposition to deposition of a normal limestone or dolomite.

Some type of cyclic sedimentation probably operates in the deposition of most sediments. Cycles should be expected in all sedimentary deposits and in all lithologies, as the general rule rather than the exception. There is evidence for five simply cycles, more or less complete, in the carbonate rocks at LeGrand.

REFERENCES

ALLING, H. L., *1943*. A metric grade scale for sedimentary rocks: *Jour. Geology*, vol. 51, pp. 259–269.

———, *1946*. Quantitative petrology of the Genesee gorge sediments: *Rochester Acad. Sci. Proc.*, vol. 9, pp. 5–63.

DEFORD, RONALD K., *1946*. Grain size in carbonate rocks: *Am. Assoc. Petroleum Geologists Bull.*, vol. 30, pp. 1921–1928.

IRELAND, H. A., and others, *1947*. Terminology for insoluble residues: *Am. Assoc. Petroleum Geologists Bull.*, vol. 31, pp. 1479–1490.

LAUDON, L. R., *1931*. The stratigraphy of the Kinderhook series of Iowa: *Iowa Geol. Survey Ann. Rept.*, vol. 35, pp. 333–451.

LAWSON, R. W., *1950*. Determination of calcite-dolomite ratios in carbonate rocks: *Iowa Acad. Sci. Proc.*, vol. 57.

National Research Council, *1948*. *Rock-Color Chart*.

WENGERD, S. A., *1948*. Fernvale and Viola limestones of south-central Oklahoma: *Am. Assoc. Petroleum Geologists Bull.*, vol. 32, pp. 2183–2251.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 195–199
FIG. 1, DECEMBER, 1951

BEACH SAND AT LOS OJOS DE AGUA DE SAN TELMO, MICHOACÁN, MEXICO

FRED M. BULLARD AND RICHARD A. MILLS
University of Texas, Austin, Texas

ABSTRACT

A sample of beach sand from a relatively inaccessible section of the Pacific Coast of Mexico is described. The mechanical analysis shows 86.82 per cent of the material in the $\frac{1}{8}$ mm grade size. The heavy mineral content is unusually high with staurolite, hornblende and hypersthene accounting for 65 per cent of the total residue. On the basis of mineral composition, the sands are believed to have been derived from igneous and metamorphic rocks in the Sierra Madre del Sur and moved northward along the coast by shore currents.

INTRODUCTION

The sample described in this paper was collected at the beach adjacent to a small settlement known as Los Ojos de Agua de San Telmo on the Pacific Coast in the western part of the State of Michoacán, Mexico. Since this is a relatively inaccessible part of the Pacific Coast and practically no information has been published on the beach sands of the Pacific coast of Mexico, it seems worth while to record the results of this brief study. During the summer of 1950 the senior author was a member of the staff of The University of Texas Geography Field School which carried on studies in the coastal section of Western Michoacán. The senior author is indebted to Dr. Donald Brand, Chairman of the Department of Geography of The University of Texas and Director of the Field School, for the opportunity to visit this area and to collect the samples described herein. The mechanical and mineral analyses were made by the junior author.

Los Ojos de Agua is in the extreme western part of the rugged Sierra Madre del Sur near the western boundary of the State of Michoacán. The mountains, which trend in a general east-west direction, reach an average elevation of from 6,000 to 7,000 feet with a few peaks approaching 10,000 feet. The mountains rise abruptly from the coast, in some places actually projecting into the sea as promontories. The few streams in the immediate area rise in the mountains and flow with steep gradients into the sea. The Río Coahuayana, one of the major streams of the area, empties into the Pacific Ocean at Boca de Apiza, about 5 miles northwest of the beach at Los Ojos de Agua de San Telmo. The Río Balsas, which empties into the sea about 125 miles to the southeast, is the chief drainage of this general region of Mexico. The climate is tropical with the rainy season coming in the summer months. The western boundary of Michoacán, marked by the Río Coahuayana, can be reached by car or bus from Colima at all seasons of the year. During the dry season, trucks cross the river and Boca de Apiza and Los Ojos de Agua can be reached over primitive roads. During the rainy season the area is accessible only on foot or horseback.

GEOLOGIC SETTING

The rocks making up the Sierra Madre del Sur are largely Cretaceous limestones which attain a thickness measured in thousands of feet. Extensive igneous activity, which began in the Tertiary and has continued to the present, has buried much of Mexico under a mantle of volcanic debris. In the coastal area the volcanic mantle has been largely removed by erosion, except in those areas where it has been preserved by faulting. Post-

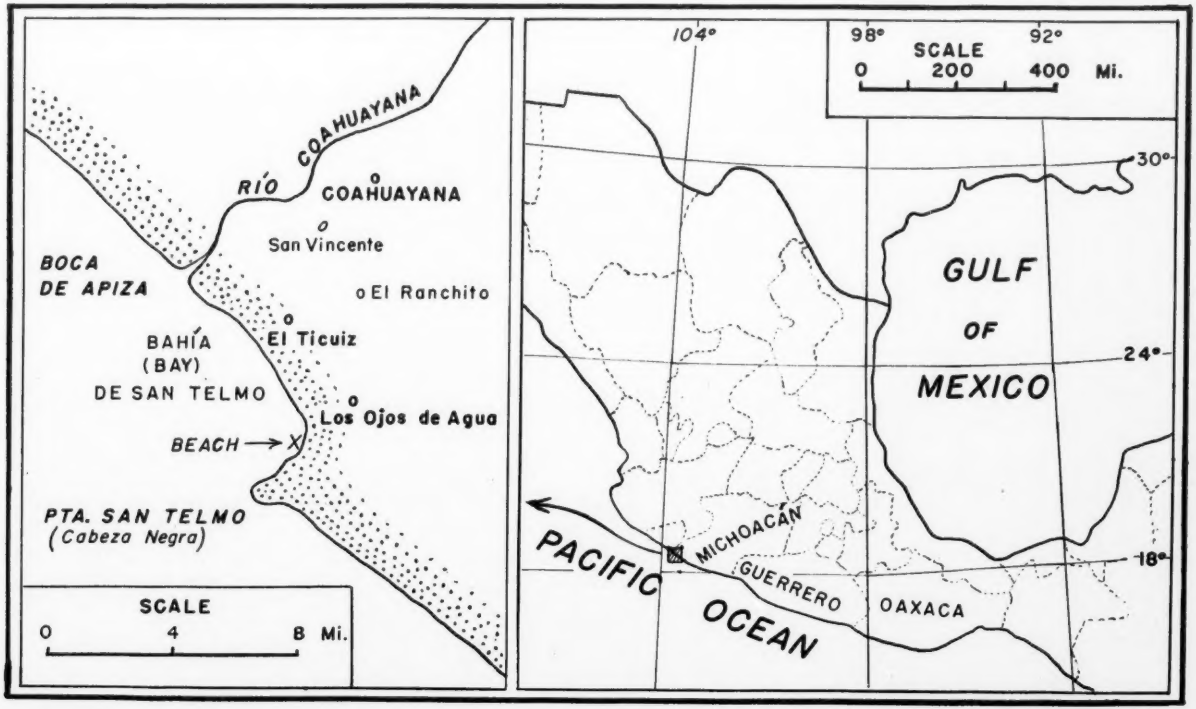


FIG. 1.—Index map of Mexico showing location of San Telmo Beach (left) and enlarged sketch of area (right).

Cretaceous intrusions of granodiorite, granite, and to a lesser extent diorite, are numerous in the coastal area. To the west of Colima the intrusions are not extensive and occur only in isolated patches. However, they become progressively more abundant to the south and east until along the Guerrero and Oaxaca coasts they form extensive areas. These intrusions, according to Palmer (1928), metamorphosed the Cretaceous rocks so completely (forming gneisses and schists) that they have been described as Paleozoic or even pre-Cambrian metamorphics.

At Los Ojos de Agua a rugged mountain mass projects into the sea. This promontory is known as Punta San Telmo although it is also known by the name of Cabeza Negra. This mountain mass is a tilted block of Cretaceous limestone dipping about 30° to the south with the strike approximately east-west. Los Ojos de Agua is a small settlement on the north margin of the mountain about 1½ miles from the beach. The springs, which give the name to the settlement, issue from the base of the mountain, probably along a fault. A short distance from Los Ojos de Agua, in the direction of the beach, the massive Cretaceous limestone which forms the base of the ridge is replaced by a dense, hard, igneous rock which appears to be a dike cutting a thick sequence of overlying volcanic tuffs as well as the underlying limestone. The white bluffs, which are conspicuous features on the north side of Punta San Telmo are made up of volcanic tuffs while the hard igneous dike makes up the core of the promontory. The sand described in this paper was collected from a small crescent beach or cove directly west of the promontory (see fig. 1).

During the rainy season the Río Coahuayana, which discharges at Boca de Apiza some 5 miles to the northwest of Los Ojos de Agua beach, has a large volume and carries a heavy load of sediment. The ocean waters at the mouth of the river are quite muddy for some distance out from shore. Vigorous wave action keeps the mud in suspension for a considerable length of time. Apparently the prevailing shore current (at least during early summer) is to the northwest since the ocean water becomes clear a short distance to the southeast of the mouth of the river, and at Los Ojos de Agua beach the water has no trace of river sediment. On the other hand, when the coast was viewed from the prominence of Punta San Telmo, it was apparent that the sediment laden waters extend for a long distance to the north and provide material for a series of bars which are conspicuous features of the coast line to the northwest of Boca de Apiza.

Analyses of Los Ojos de Agua de San Telmo Beach Sand

Samples of the beach sand, which were collected at a small cove directly northwest of Punta San Telmo (fig. 1), were taken at normal surf level.

Mechanical analysis.—A size analysis, using standard methods of screening, gave the following results:

Mesh opening in mm	Per cent of total
½ mm	.04
¼ mm	5.52
⅛ mm	86.82
1/16 mm	7.22
Pan	.14

From the results of the mechanical analysis it is apparent that the sand is well sorted with a high concentration in the modal grain size. It is a typical beach sand in which vigorous wave action has resulted in a high degree of sorting.

Mineral analysis.—Heavy minerals are exceptionally abundant in the beach sand, so much so that the sand has a "salt and pepper" appearance. It is reported that beaches to the southeast, in the direction of the Río Balsas, are made up of black sands and in some cases what have been described as blue sands. No samples of these beaches were obtained and consequently it can only be inferred that the percentage of "heavy minerals" increases to the southeast. In the beach sand from Los Ojos de Agua the heavy residue constitutes 29.8

per cent by weight of the total sample. Bromoform was used to separate the light and heavy minerals. The heavy minerals were identified and the percentage of each species in the residue was determined on the basis of a count of 300 grains.

Results of heavy mineral analysis

(per cent by number of grains; based on a count of 300 grains)

	Per cent of total residue
Staurolite	31
Hornblende	18
Hypersthene	16
Black opaque	8
Quartz (stained with iron)	5
Pyroxene (monoclinic)	4
Calcite	2
Epidote	2
Rutile	2
Titanite	2
Apatite	rare
Garnet	rare
Unidentifiable, largely iron coated	10
Total	100

Notes on the Heavy Mineral Species

Staurolite.—The grains are angular, irregular and somewhat platy. Outstanding on all grains is the hackly to conchoidal fracture. Many of the grains appear as "chips" of glass, and under crossed nicols the bright interference colors exhibit the conchoidal fracture in a striking manner. Most of the specimens are clear with golden yellow pleochroism (X colorless, Y yellow, Z golden yellow). Inclusions of magnetite and minute rod-like crystals were abundant in a few specimens resulting in a porous or "swiss cheese" appearance. Many of the grains are stained or coated with hematite and leucoxene making identification difficult.

Hornblende.—The grains are usually elongate or prismatic and deeply colored either dark brown or dark green. At first glance the grains appear to be opaque but with convergent light the characteristic hornblende pleochroism can be observed. Actually, it was found that the best way to study the grains was to use a small tungsten filament lamp and project an intense light on the grain. In normal light, due to the dark color, the birefringence as well as the pleochroism is difficult to observe. All of the specimens are free of inclusions and they do not appear to be badly weathered.

Hypersthene.—The grains are worn elongate or stubby and may be described as subcylindrical. The ends generally are rounded; however, the general fracture pattern varies from even to subconchoidal. The most outstanding property is the strong pleochroism which ranges from a brownish pink (X) to a greenish yellow (Y) to a dark green (Z). While some grains are clear (usually those with conchoidal fracture) most of the grains contain brown, thin, plate-like inclusions (schiller structure) and conspicuous striations parallel to the cleavage and a marked cross fracture. Inclusions are numerous but they are small and difficult to identify. A few specimens were obscured by iron stains.

Black opaques and unidentifiable grains.—The black opaques in these sands are rare and they are not readily identified. One difficulty is that a large number of grains, especially staurolite and quartz, have been stained or coated with hematite and leucoxene. Therefore, very often grains that appear opaque in ordinary light are observed under crossed nicols to be a mineral that has been nearly covered by an opaque, but still shows some birefringence. In the case of staurolite, a faint yellow pleochroism will be observed on an exposed edge. In many cases, however, it is not possible to identify the mineral. Iron stained quartz is not difficult to identify because of its low birefringence, which usually can be observed on the edges. The true opaque minerals include only ilmenite, magnetite and hematite.

Pyroxenes (monoclinic).—The grains are slightly rounded, prismatic to stubby and range from nearly colorless to yellowish brown in color. The high extinction angle serves to identify the species.

Calcite.—This somewhat unusual associate of detritals is characterized by large, well rounded grains which show a marked (twinkling) change in relief on rotation of the stage. The grains are light brownish yellow to colorless with the characteristic cleavage and high order interference colors.

Epidote.—The few specimens were subangular fragments, greenish yellow in color and exhibiting distinct pleochroism. Many of the fragments give the typical centered optic axis (compass needle) interference figure.

Rutile.—Only a few grains are represented in these sands and they are elongate prisms ranging from dark reddish brown to nearly opaque.

Garnet.—The few grains of garnet are small, transparent, angular fragments.

CONCLUSIONS

The predominance, both in species and per cent, of minerals characteristic of metamorphic rocks and primary igneous rocks indicates that the major part of the beach sand was derived from the intrusives and the metamorphics in the adjacent Sierra Madre del Sur. The relatively fresh appearance of many of the species as well as the presence of calcite, indicates a nearby source. The extensive metamorphism produced by the igneous intrusions, which are so common in the coastal area of Michoacán, Guerrero and Oaxaca, undoubtedly provided the material which the streams (largely the Río Balsas and its tributaries) carried to the Pacific Ocean and northward moving shore currents transported the sands along the coast.

REFERENCE

PALMER, ROBERT, *1928*. The rudistids of Southern Mexico: *California Acad. Sci., Occ. Papers*, no. 14.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 200–204
FIGS. 1–6, DECEMBER, 1951

THE OCCURRENCE AND DERIVATION OF AN AUGITE-RICH BEACH SAND, GRENADA, B.W.I.

H. S. BENNETT AND P. MARTIN-KAYE
Trinidad Leaseholds Limited, Trinidad, B.W.I.

ABSTRACT

The beach sand, containing up to 93% of augite in samples, is described with respect to the variation along the beach of its grain size and heavy mineral content, and the optical properties of the different heavy mineral grains are given. A brief description is included of the geology of the immediate hinterland with reference to the source of the beach sand.

INTRODUCTION

Although the peculiarity of a small, deeply indented bay in Grenada, British West Indies, has long partly been recognized in so far as the name Black Bay has appeared on maps for over a hundred years, no mention has been encountered in geological literature concerning the occurrence of a remarkably rich augite beach sand which is to be found at this locality. The bay is situated on the southern side of Point Saline, which itself forms the S.W. extremity of the island (fig. 1), and it is to the colour of the beach that the name Black Bay, refers (fig. 2). The beach is made up of a black sand, composed almost entirely of heavy minerals, with augite predominating. The minerals have been concentrated from a moderately consolidated tuff which forms the greater part of Point Saline and its vicinity.

From the admittedly rather limited amount of information on black sands available to the writers, it seemed that such an accumulation of augite is a rarity which warranted investigation. Consequently the beach was systematically sampled and the source of its material determined.

BLACK BAY BEACH SAND

The results of mechanical and heavy residue analysis of a series of 6 samples taken at 50 yard intervals along Black Bay beach, which approximate 250 yards in total length, are represented graphically in figures 3–6. In all samples the heavy residue content is high, ranging from 97 per cent at the western end to almost 100 per cent in the east. In addition to the dominant augite, grains of magnetite and hypersthene are also present. As can be seen from figures 4 and 5, illustrating the mineral distribution in the naturally-occurring sand, and in the 0.105–0.125 mm grain size fraction respectively, the augite/magnetite ratio is not constant throughout. In the case of the smaller grains 0.105–0.125 mm, magnetite is scarce in the western half of the bay but increases in frequency fairly sharply to a maximum of 72 per cent at the eastern end. In the sand taken as a whole, however, this increase does not occur until approximately 75 yards from the eastern end where it reaches a maximum of 47 per cent.

In addition to mineral sorting, there is also sorting of grain size as illustrated by the cumulative curves (fig. 6). From these it can be seen that there is a comparatively marked difference in grain size between the two end samples, although it is almost constant for the intervening distance. These curves give the modal grain size as lying high in the medium grain size range of the Wentworth scale. The exact relationship between mineral distribution and grading is not clear, although it is observed that there is much more augite in the coarser-grained western end than the finer-

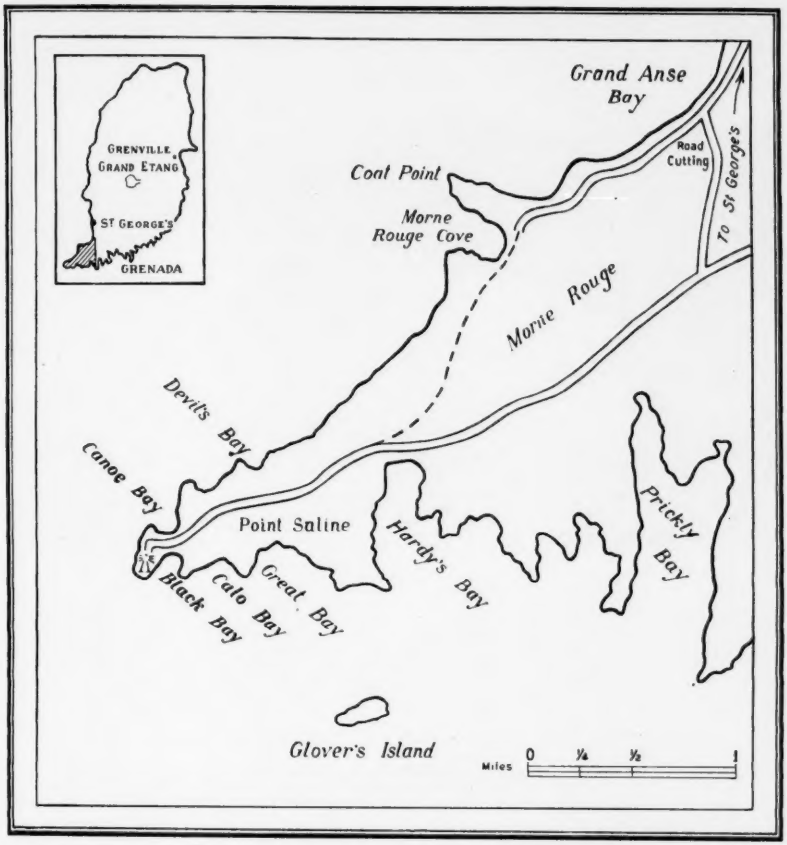


FIG. 1.—Location of Black Bay, Grenada, British West Indies.

grained eastern end where the magnetite is more concentrated.

The augite grains are remarkably fresh, displaying all degrees of rounding, although the most common shape is sub-angular. Good crystal shapes also occur. Colour varies within shades of yellowish green, and the pleochroism, where present, is generally from dark green to medium brown but sometimes from dark to light green. Inclusions of iron ore are common.

The few grains of hypersthene present (maximum 1.8 per cent heavy minerals) are usually small and angular, many showing a marked pleochroism from deep brown to nearly black. Magnetite grains are small and generally rounded, but some show their octahedral crystal shape. The balance of the grains in the sand, i.e., the light residues, consist of calcite, fragments of corals and marine shells, and a few grains of quartz.

The concentration of heavy minerals in the neighbouring Calo Bay increases from 23 per cent to 62 per cent from west

FIG. 2.—Black Bay beach, Point Saline, Grenada, British West Indies.

to east, i.e., in the same direction as in Black Bay. Augite constitutes almost the entire residue, magnetite being very rare. However a single sample from Canoe Bay, a few yards north of Black Bay on the other side of the Point, gave a 40 per cent heavy residue, augite and magnetite being present in a ratio approximately 3:1.

DERIVATION OF BEACH SAND

A brief reconnaissance of the region shows that the undulating landscape of Point Saline is formed from a moderately consolidated and thickly bedded tuff.

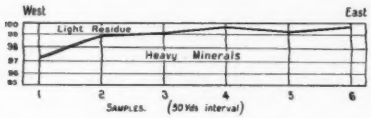


FIG. 3.—Percentage distribution of light and heavy minerals along Black Bay beach.

The bedding is mainly horizontal, as is seen in the good coast section exposed by the steep cliffs of Point Saline and at Black Bay. Thin calcite veins are fairly common throughout the rock and the top ten feet on the headland, at the eastern end of the bay, is heavily indurated with this mineral. Inland the countryside becomes more rugged, partly due to the outcrop of masses of augite diorite and well bedded agglomerates. At Morne Rouge Road Junction Cutting, the tuffaceous sediments of Point Saline can be seen overlying a conglomeratic bed, which in turn, rests upon an exposure of exfoliating augite diorite.

Thin sections of the diorite show that large euhedral crystals of pale yellow ferriferous augite ($Z \wedge c = 48–52°$) are common. Zoned and twinned crystals are frequent, occasionally showing distinct pleochroism (light green to light reddish brown). These properties, therefore, concur with those often exhibited in the

beach sand. Other minerals include plagioclase laths (andesine/labradorite), frequent magnetite, a few small aggregates of quartz, occasional hypersthene and very rare biotite. Hornblende is absent.

The tuff in thin section is found to contain comparatively large and generally angular fragments of the augite diorite, and of augite and plagioclase as well as smaller grains of augite, plagioclase, magnetite and quartz. These constituents are set in a groundmass of very fine red clayey material similar to that encountered in the weathering channels of the exfoliating outcrop of augite diorite. The

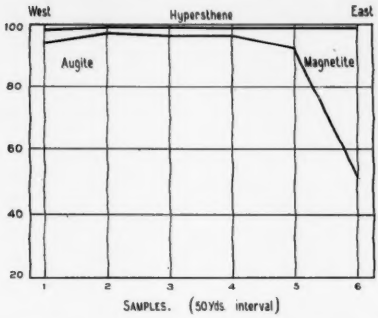


FIG. 4.—Percentages of augite, magnetite, and hypersthene in the heavy residues of beach samples.

augites present closely compare also with those found in the diorite.

The similar optical properties of the augites suggest that the tuffs at Point Saline have supplied the heavy minerals of Black Bay beach. In fact the proximity of the tuff to the beach makes this the obvious source. It also seems clear that the tuff was derived from the same magma as the augite diorite.

The absence of fossils in the tuff did not permit any age determination to be made. It seems probable, however, that it is not very old; minor manifestations of volcanic activity have occurred in recent years.

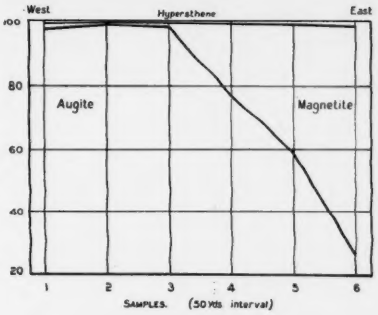


FIG. 5.—Percentages of augite, magnetite, and hypersthene in 0.105–0.125 mm heavy mineral fraction of beach samples.

Each phase of volcanicity must have been sufficiently violent and prolonged in order to supply enough material, at each eruption, for the adequate burial and hence preservation of the majority of the augites.

Present day erosion is rapid since almost unaltered augites can be seen exposed in the vertical cliff sections. Once the crystals are on the beach, any decomposed material is removed as soon as formed by wave action. This would account for the remarkably fresh appear-

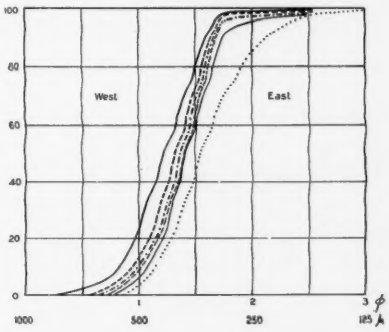


FIG. 6.—Cumulative grain-size curves of samples taken W—E along Black Bay beach.

ance of the mineral in the Black Bay sand.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Directors of Trinidad Leaseholds Limited for permission to publish this article, and for the use of the facilities of the Geological Laboratory at Pointe-à-Pierre. We are also grateful to Dr. H. B. Milner for kindly reading the proofs of this article.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 205–212
FIGS. 1, 2, DECEMBER, 1951

PEBBLES FROM A POTHOLE: A STUDY IN SHAPE AND ROUNDNESS

DOROTHY CARROLL
New South Wales, Australia, and Bryn Mawr College, Bryn Mawr, Pennsylvania, U.S.A.

ABSTRACT

An assemblage of pebbles collected from a pothole in even-grained sandstone is described. Variation in shape and roundness for the different lithologic types of pebbles is given. The influence of original shape of the piece of rock worn into a pebble is stressed, and a series of stages in abrasion is described. The observations are compared with the facts and principles obtained by experiments on pebble abrasion by workers elsewhere, and it is believed that the experimental principles are exemplified by this sample of pebbles abraded in a pothole.

INTRODUCTION

Lord Rayleigh (1942 and 1944) has described experiments for the production of rounded pebbles and has commented on the scarcity of spherical pebbles in the natural material available to him. In order to obtain some information about the occurrence of pebbles in potholes, a number of observations were made in stream beds of Triassic sandstone (the Hawkesbury Sandstone) in the vicinity of Sydney, New South Wales. Potholes are very plentiful in all the beds of streams which flow over sandstone, but it was found that the flow of water was insufficient to move the pebbles in the holes except after the heavy falls of rain which are common in this part of the country at all times of the year.

In most stream beds examined, the conditions for the production of rounded pebbles in potholes are all present: an irregular floor of jointed medium- to coarse-grained sandstone in which potholes have been worn; a supply of more or less angular pieces of sandstone and shale for the production of pebbles; obstructions in some holes of large pieces of sandstone which act as additional abrasive surfaces and cause extra swirling of the water; and sand added by the stream to act as a fine abrasive agent.

The pothole from which the sample of pebbles described was collected, is fairly large and is situated on a flattish platform of sandstone about thirty yards from the foot of a waterfall in the Valley of the Waters, Wentworth Falls, in the Blue Mountains, fifty miles west of Sydney. The country rock is well-bedded Hawkesbury Sandstone containing some prominent shale bands; it has strong vertical jointing. The pothole had resulted from erosion against a joint plane and measured 8 feet 6 inches by 4 feet 6 inches and was 2 feet 6 inches deep. It is therefore not a typical pothole of circular plan. It contained three large boulders, two of coarse sandstone, and the third of fine sandstone. The measurements of the boulders were $18\times19\times6$ inches, $25\times30\times12$ inches, and $19\times19\times3$ inches respectively. Coarse and fine sand, separated from each other by water action, and weighing about 20 to 30 pounds was situated near the two largest boulders. The stream does not normally flow into this pothole except during floods. Seventy-seven pebbles, practically all that the hole contained, were collected from it for examination.

METHOD OF EXAMINATION

Each pebble in the sample was numbered. The lithological type, size, shape, and roundness of each was recorded by methods recently described (Carroll, Brewer, and Harley, 1950). These briefly are:

TABLE 1.—*Size distribution of pebbles*

Grade mm	8–16	16–32	32–64	Range mm	Median mm	No. of Pebbles
	%	%	%			
Coarse sandstone and grit	—	63.6	36.4	19.9–43.9	26.7	22
Medium sandstone	11.8	58.8	29.4	12.2–41.5	26.4	17
Fine sandstone	3.3	76.5	20.2	14.8–38.9	28.1	18
Shale	20.0	60.0	20.0	9.7–45.7	26.6	15

Lithologic type: by visual inspection following Plumley (1948) and Allen (1949).

Size: by measurement with a gauge.

Shape: determined by Krumbein's (1941a) intercept method which is based on a triaxial ellipsoid as the reference solid to which a pebble is compared. The three diameters measured are, *a*, long, *b*, intermediate, and *c*, short. The sphericity is found from Krumbein's chart with the Zingg (1935) pebble shape added. In Zingg's classification naturally occurring pebbles fall into four groups: disc-shaped (oblate spheroid), spherical (spheroid), blade-like (triaxial), and rod-like (prolate spheroid).

Roundness: determined visually by comparison with Krumbein's (1941) pebble images.

DESCRIPTION OF PEBBLES

Lithology.—The distribution of rock types present was: coarse-grained sandstone (13); medium-grained sandstone (17); fine-grained sandstone (18); grit or gritty sandstone (9); sugary and porous sandstone (2); shale, red and purple (15); milky quartz (3), giving a total of 77 pebbles. The sample of pebbles is, therefore, a fairly homogeneous one since 59 of the pebbles are of sandstone. The terms "coarse," "medium," "fine" and "grit" are used in the sense of Wentworth's grade scale (1922a).

Size.—The mechanical composition is given in table 1 in which the pebbles are grouped lithologically. The size is taken from the mean diameter which was obtained from the shape measurements by Krumbein's method. It is to be noted that all the pebbles are between 8 and 64 mm diameter and therefore fall in Wentworth's pebble grade. The maximum grade is 16 to 32 mm.

Shape and Roundness.—Table 2 gives

TABLE 2.—*Shape and roundness of pebbles in the 16–32 mm grade*

Pebbles	Shape Class[1]				Sphericity		Roundness	
	I	II	III	IV	Range	Av.	Range	Av.
Grit or gritty sandstone (9)	3[2]	3	1	2	.44–.78	.67	.4–.6	.5
Other grades	—	—	—	—	—	—	—	—
Coarse sandstone (7)	3	4	—	—	.65–.90	.75	.5–.6	.6
Other grades (6)	2	—	3	1	.54–.78	.66	.3–.9	.6
Medium sandstone (10)	3	6	1	—	.51–.90	.75	.3–.9	.6
Other grades (7)	1	3	1	2	.50–.90	.70	.4–.9	.6
Fine sandstone (13)	6	1	3	3	.41–.79	.60	.3–.8	.5
Other grades (5)	2	—	1	2	.60–.71	.68	.5–.8	.6
Shale (9)	6	2	1	—	.49–.82	.69	.3–.6	.5
Other grades (6)	4	—	—	2	.49–.70	.60	.3–.6	.5

[1] The Zingg shape classes are: I. disc-shaped; II, spherical; III, blade-like; IV, rod-like.
[2] Figures all refer to numbers of pebbles.

the shape and roundness of the different lithologic types in the maximum grade (16–32 mm) and compares these with the remaining pebbles in the sample.

DISCUSSION

Relationship between Shape and Lithological Type

The results of abrasion on a piece of rock produce what is termed a pebble, and a certain degree of roundness, i.e., lack of sharp edges, is implicit in the term (see Oxford Dictionary). American writers have made a definite distinction between the concept of shape and roundness (Krumbein, 1941a) for descriptive purposes, but it is difficult to keep these concepts clear when the reduction of a piece of rock by abrasion results in a definite relationship between the shape and roundness (Rayleigh, 1942, p. 118), and the amount of abrasion. It has been considered that abrasion will produce a spherical shape from any piece of rock of fairly homogeneous character provided the process is continued for sufficiently long. Rayleigh (1942, p. 108) has pointed out that if the three principal axes of the original piece of rock prior to abrasion are not very different, i.e., the shape approaches that of a cube, the spherical form is continually approached as attrition proceeds. If the original piece of rock is that of a solid rectangle (parallelepiped) then a rod-like, tabular, or bladed pebble will be produced. The lithological type, therefore, is of subordinate importance, the original shape being caused by lamination and jointing of the rock which is undergoing weathering to produce the raw material of the pebbles. For example, if a piece of shale of compact type is cut mechanically into a cubic shape, abrasion will cause the production of a spherical pebble, whereas naturally occurring shale fragments will tend to be rectangular and from these disc-shaped pebbles will be produced if the beds are thin, and rod-like pebbles if the bedding is thicker and the rock more compact.

It has been generally stated that even-grained compact rocks produce pebbles of greater sphericity and roundness than do other types of rocks, and the observations recorded here confirm this statement, the medium-grained sandstones having produced the greatest number of spherical pebbles. Table 3 summarizes the distribution of shapes in the lithological types.

Effect of Size on Shape

Figure 1 shows the relationship between size (mean diameter) and shape (as sphericity) of the individual pebbles. There appears to be very little relationship between size and shape of the pebbles in this sample.

Effect of Size on Roundness

Figure 2 shows the relationship between size (mean diameter) and round-

TABLE 3.—*Shapes of pebbles of different rock types*

Rock type	Description of parent rock	Shape (Zingg)			
		I Disc	II Spherical	III Blade	IV Rod
Grit	Irregular bedding	3[1]	3	1	2
Coarse sandstone	Irregular at base of other sandstones	5	4	3	1
Medium sandstone	Thick evenly bedded	4	9	2	2
Fine sandstone	Thin beds	8	1	4	5
Shale	Thin beds	10	2	1	2
Totals		30	17	11	12

[1] Numbers of individuals, not percentages.

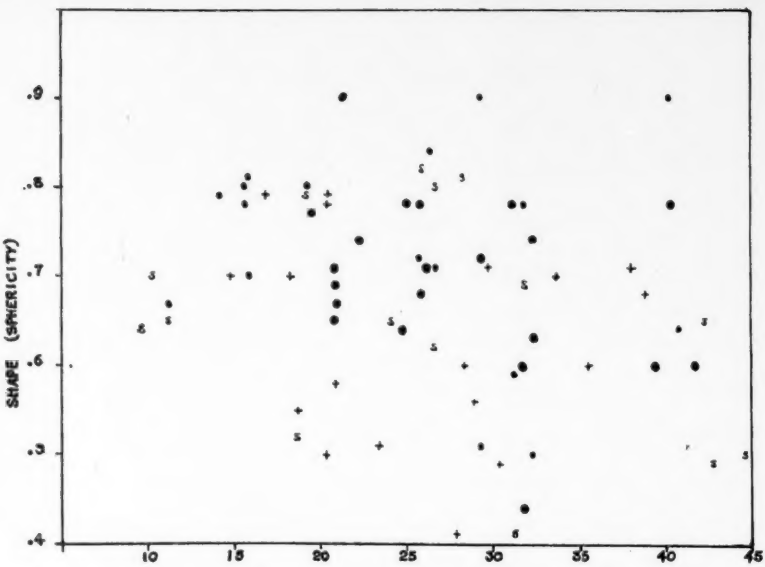


FIG. 1.—Relationship between shape (sphericity) and size (mean diameter) of individual pebbles.

ness of the individual pebbles. The graph indicates that there is a relationship between roundness and size and that the majority of the pebbles occur in the 0.5 and 0.6 roundness groups. This may be the limiting value for this particular environment.

Special Features Due to Abrasion

Apart from the shape and degree of roundness of the surfaces of the pebbles caused by abrasion there are some special features produced. One of these features is a modification of shape by a flattening at the poles as illustrated by Rayleigh (1942, pl. 1, figs. 2 and 3). Such pebbles do not exhibit a true elliptic shape but bulge away from an inscribed ellipse. Other pebbles exhibit a concave face, generally on one side only. These have been produced experimentally by Rayleigh (1942, p. 116) by causing pieces of material of the same size to be moved together in a vessel representing the conditions of a pothole; in the resulting abrasion some pieces of rock shield others, and it was found that this shielding takes place more towards the outside of a pebble, thus allowing blows on the original flat surface which becomes pitted and worn until eventually a concavity is produced. In this sample of pebbles concavities of this type, and presumably of this origin, were found in six coarse sandstone pebbles (No. 22 is a particularly good example with a distinct concavity in five of its six rectangular faces); seven medium sandstone pebbles; nine fine sandstone pebbles; and four shale pebbles. The type of concavity is illustrated by Rayleigh (1942, pl. 1, fig. 6).

Stages in Abrasion of Pebbles

In any sample of naturally occurring pebbles it is not to be supposed that all the original rock fragments arrived at the site of abrasion, in this particular instance a pothole, at the same time nor

that each has been subjected to the same amount and intensity of abrasion. Some may be the remains of the original pieces of rock which assisted in the formation of the pothole and these received a well-rounded form in the process. In a small pothole this may be so, but in a large one, such as that described here, with well-worn sides and base, it is probable that the original pebbles have disappeared, although it is also possible that the addition of new angular pieces of rock may protect some pebbles, particularly the smallest, from further abrasion. The fact that the majority of the pebbles in this sample are of fairly uniform size would indicate that there is a factor in mechanical abrasion in such a situation which prevents any great reduction in size below this general uniformity.

If the size of the individual pebbles in the sample is examined statistically it is found that the distribution in sizes is as follows:

	1st Quartile (mm)	Median (mm)	3rd Quartile (mm)
Coarse sandstone and grit	22.8	26.7	33.8
Medium sandstone	16.9	26.4	32.2
Fine sandstone	20.3	25.6	30.4
Shale	18.6	26.6	31.7

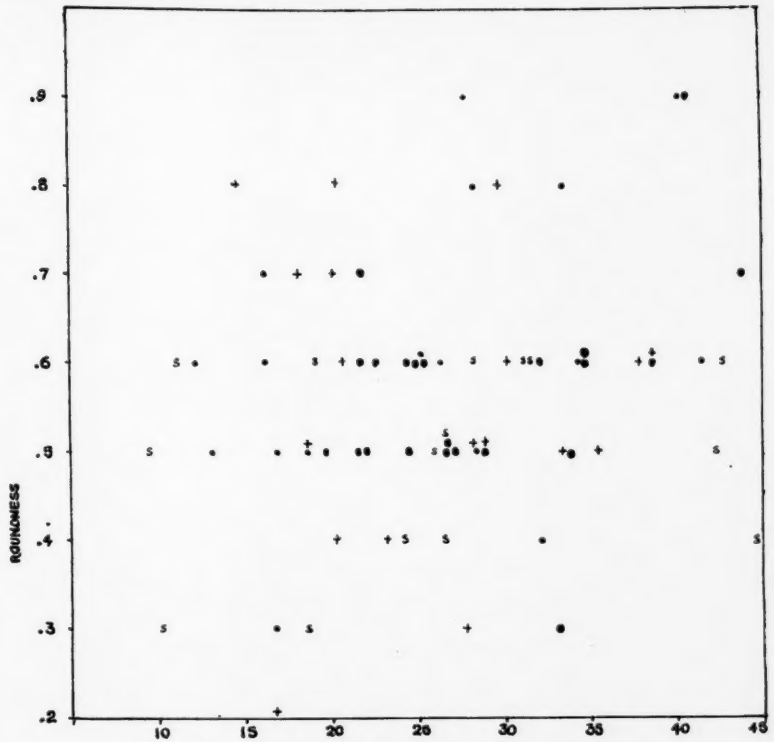


FIG. 2.—Relationship between roundness and size (mean diameter) of individual pebbles.

It can be seen from an examination of these figures and those of table 1, that there is a restricted range in sizes of pebbles from this pothole, which may not, and in fact does not, occur in all the potholes observed. The size uniformity may be caused by the large size of the pothole and the superior opportunities for abrasion among a large number of pebbles in rather restricted circumstances. It is probable that abrasion in this situation would be more rapid that in smaller potholes capable of containing fewer pieces of rock to become worn.

It is interesting to compare the shape and roundness of the pebbles of median size:

	Actual dimensions (mm)	Shape (sphericity)	Roundness
Coarse sandstone and grit	33.0×29.2×17.8	.78 (I)	.5
Medium sandstone	34.2×25.4×17.8	.72 (II)	.6
Fine sandstone	40.6×25.4×14.0	.60 (III)	.5
Shale	38.0×30.5×11.4	.80 (II)	.5

The pebble showing the greatest sphericity and roundness in each lithological type:

	Dimensions (mm)	Shape	Roundness	Identification
Coarse sandstone	50.8×43.2×28.0	.78 (I)	.9	2
Medium sandstone	44.5×42.0×34.2	.90 (II)	.9	10
Fine sandstone	25.4×22.8×12.7	.78 (I)	.8	57
Shale	34.2×30.5×20.4	.81 (I)	.6	37

No. 2, second largest in group; No. 10, second largest in group; No. 57, at the 1st. quartile; No. 37, next to the median.

The pebble showing the least sphericity and roundness in each lithological type:

	Dimensions (mm)	Shape	Roundness	Identification
Coarse sandstone	53.5×28.0×17.8	.60 (III)	.3	12
Medium sandstone	50.8×25.4×20.4	.59 (IV)	.4	31
Fine sandstone	50.8×25.4×7.6	.41 (III)	.3	42
Shale	28.0×22.8×5.2	.52 (I)	.3	60

No. 12, at 3rd quartile; No. 31, at 3rd quartile; No. 42, near median; No. 60, at 1st quartile.

It might be argued that the smallest pebbles, having presumably been reduced in size by abrasion, would show the greatest degree of roundness, and the largest pebbles the greatest angularity. That this is not so indicates that pebbles may have been added at various times at various sizes and initial shapes.

Rounding by Abrasion

It has been noted earlier that original shape influences the final shape of a pebble produced by abrasion. Krumbein's (1941) pebble chart of the degrees of roundness gives some idea of the stages which might be passed through to reach a perfectly rounded pebble, that is, a pebble in which the radii of inscribed circles in the corners, if any, are of the same magnitude as those of the largest inscribed circle for the pebble. Figure 2 shows that the majority of pebbles in this sample have a roundness of 0.5 or 0.6. The actual percentages of pebbles of all types are: R=0.2–0.4, 16 per cent; 0.5, 30 per cent; 0.6, 35 per cent; 0.7–0.9,

19 per cent. Thus the pebbles as a whole are well rounded and have no sharp edges, the group R = 0.4 being the highest degree of roundness of a particle in which angularity is shown, pebbles of group R = 0.5 and upwards having notably smooth edges. All stages in the rounding of this particular sample may not, however, have taken place in the pothole as some transport by the stream, which is in an extremely steep and narrow gully with a drop of several hundred feet, would be necessary to move the pieces of rock to the pothole.

It is obvious that only six pebbles of groups 0.2 and 0.3 have not suffered much abrasion and can be regarded as new arrivals in the pothole. Similarly the pebbles in groups 0.7, 0.8, and 0.9 (13) are probably the pebbles which have been longest in the pothole as they are the most perfectly rounded. The size of the pebbles appears to have little significance as the least rounded pebble, i.e., the one with the most angular edges is one of the smallest. The three pebbles in the 0.9 group are rather on the large size.

Considering lithological types it is seen that shale pebbles have not become more rounded than 0.6 which may be a maximum for this type of rock. Fine, medium, and coarse sandstone are contained in groups 0.7 to 0.9; only two pebbles of medium sandstone and one of coarse sandstone reach a maximum of 0.9.

Comparison of Observations with Experimental Work

The principles relating to wear or abrasion of particles of pebble size have been elucidated by tumbling-barrel and other experiments arranged to simulate natural conditions. Krumbein (1941b) has summarized these results and enumerated the changes in size, shape, and roundness of pebbles which have been found. It has been found that size will be continually reduced, and that roundness and sphericity increase during abrasion in a tumbling-barrel. Krumbein has graphed the change in roundness and sphericity against the distance of travel. These two attributes may approach limiting values which may depend on certain initial values. In his experiments the limiting value for roundness was about 0.64 and for sphericity about 0.77. It is interesting to note that this limiting value for roundness is very similar to that found for this particular sample of pebbles (see fig. 2). Experimentally, too, it was found that rounding proceeded ten times as rapidly as sphericity change, a fact suggested by figure 1, in which there appears to be little relationship between size and sphericity. The shape changes only slightly during abrasion, so that the end-product will generally show traces of the original inherited form. Figure 2 shows also that some of the larger pebbles are the better rounded, suggesting that size has some influence on rounding.

Rayleigh (1942, p. 110) has given some useful concepts concerning change of shape (which is actually roundness as defined here) of pebbles which relates to the rigor of the process of abrasion. If the original shape of a piece of rock is ellipsoidal and in any given case (observed experimentally) is found to be unaltered, the rate of abrasion at the ends must be as the fourth root of the specific curvatures at these ends. He has found experimentally that abrasion directly disturbs the ratio of axes but that some forms under certain conditions can maintain their shape. Pebbles having a perfectly spherical shape are rare in nature and are not produced unless the original pieces of rock had their three principle axes nearly equal, thus, in general, few spherical pebbles will be produced. The very well-rounded spherical pebbles, such as those illustrated by Dunn (1911), whose collection is now in the British Museum of Natural History, have probably been produced in potholes.

The results of abrasion studies have been applied to stream gravels by Wentworth (1919), Krumbein (1940), Plumley (1948), and others and it has been found that the general nature of the rounding curves agrees well with natural instances, and that the size decrease of

pebbles was of the type indicated by the data. The present observations indicate that it is also possible to apply such findings to abrasion of pebbles in a pothole, although it is not possible to estimate the rigor of the process as miles of travel in such a situation.

CONCLUSIONS

The majority of the pebbles collected from this particular pothole show a considerable degree of rounding but only two pebbles have a high sphericity as well as being nearly perfectly rounded; these are of coarse and medium-grained sandstone. The scarcity of spherical well-rounded pebbles is caused by two factors: the original shape and the compact homogeneous nature of the rock. Pebbles which have been abraded in potholes tend to show a distinctive form which is caused by abrasion in a confined space, and which differs from that produced in other parts of stream beds or in marine situations (except in potholes on low rocky shore platforms subject to wave and tidal action). Abrasion in a pothole appears to be much more effective in producing well-rounded forms than in other situations.

The observations on roundness and shape appear to agree with those found by experiment, though the ratios of rounding to size decrease, sphericity to size decrease, and rounding to sphericity change cannot be obtained as in Krumbein's experiments (1941b, p. 494). There is however, some indication that roundness has approached a limiting value for the environment of this sample, and that there is some influence whereby the size tends to approach a median value (table 1 and first tabulation). Sphericity change has not been as marked as roundness change. Original size may have influenced roundness and this may also be an influence of the total assemblage of pebbles.

REFERENCES

ALLEN, P., *1949*. Wealden Petrology: The Top Ashdown Pebble beds and the Top Ashdown Sandstone: *Quart. Jour. Geol. Soc.*, vol. 104, pp. 257–321.

CARROLL, D., BREWER, R., and HARLEY, J. E., *1950*. Pebbles from the Upper Hunter River Valley, New South Wales: *Royal Soc. New South Wales Jour. and Proc.*, vol. 83, p. 251.

DUNN, E. J., *1911*. Pebbles: George Robertson, Melbourne.

KRUMBEIN, W. C., *1940*. Flood gravel of San Gabriel Canyon, California: *Geol. Soc. America Bull.*, vol. 51, pp. 639–676.

———, *1941a*. Measurement and geological significance of shape and roundness of sedimentary particles: *Jour. Sedimentary Petrology*, vol. 11, pp. 64–72.

———, *1941b*. The effects of abrasion on the size, shape, and roundness of rock fragments: *Jour. Geology*, vol. 49, pp. 482–520.

PLUMLEY, W. J., *1948*. Black Hills terrace gravels: A study in sediment transport: *Jour. Geology*, vol. 56, pp. 526–577.

RAYLEIGH, LORD, *1942*. The ultimate shapes of pebbles, natural and artificial: *Royal Soc. London Proc.*, Series A, vol. 181, pp. 107–118.

———, *1944*. Pebbles of regular shape and their reproduction in experiment: *Nature*, vol. 154, no. 3901, pp. 169–171.

WENTWORTH, C. K., *1919*. A laboratory and field-study of cobble abrasion: *Jour. Geology*, vol. 27, pp. 507–522.

———, *1922a*. A scale of grade and class terms for clastic sediments: *Jour. Geology*, vol. 30, pp. 377–392.

———, *1922b*. The shapes of pebbles: *U. S. Geol. Survey Bull.* 730.

ZINGG, TH., *1935*. Beitrag zur Schotteranalyse: *Schweiz. min. pet. Mitt.*, vol. 15, pp. 39–140.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, No. 4, P. 213
DECEMBER, 1951

SYMPOSIUM ON PALEOECOLOGY OF SHALE AND EVAPORITE DEPOSITION

This symposium was presented by the Society of Economic Paleontologists and Mineralogists in St. Louis, Missouri on April 26, 1951, during its annual meeting. The complete symposium consisted of the following papers:

Microfossils as environment indicators in marine shale. Samuel P. Ellison, Jr.

Depositional environment of red and green shales. Ralph E. Grim.

Relationship of biotic and lithic facies in Recent Gulf Coast sedimentation. Shepard W. Lowman.

Depositional environment of black shale. Parker D. Trask.

Significance of evaporites in depositional sequence. L. L. Sloss.

The first three of these papers are published in the following pages. Manuscripts of the remaining papers of the symposium have not been recieved by the *Journal*, but it is hoped that the papers can be published in subsequent issues.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 214–225
FIGS. 1–7, DECEMBER, 1951

MICROFOSSILS AS ENVIRONMENT INDICATORS IN *MARINE SHALES*[1]

SAMUEL P. ELLISON, JR.
University of Texas, Austin, Texas

ABSTRACT

Interpretations of depositional environments from microfossils are based mainly on comparisons of fossil assemblages with the micro-organic remains in present day sea muds. Qualitative comparisons of species, genera, and families common to both shales and sea muds have provided two broad generalizations. First, benthonic organisms are the chief indicators of temperature, depth, amount of light, water composition, and other bottom conditions. Second, pelagic, planktonic, and nektonic organisms overlap into a variety of sedimentary environments indicating only broad latitudinal boundaries of temperature and salinity.

Quantitative studies of micropopulations provide the best data from which to reconstruct the environments of deposition. Furthermore, quantitative data give promise of being new stratigraphic correlation tools, their importance ranking with lithologic and electrical logs.

Five important basic principles apply to microfossils if they are employed to determine environmental conditions. First, microfossils are integral parts of the lithology of shales. Since the specimens are particles of sediments, then the fossils and the lithology should be considered a closely knit result of the whole environment. Second, specimens are derived simultaneously from the living (biocoenosis), the dead debris (thanatocoenosis), and agents of sedimentation (wave action, currents, turbidity currents, mud slides, and organisms). Third, in the processes of sedimentation, gravity moves micro-organic remains to deeper locations on the ocean floor. Consequently, the upper depth and temperature limits of living organisms are the keys to depth and temperature interpretations. Fourth, the use of biological ecology data for comparisons with microfossil suites brings in only the biocoenosic elements and omits the results of sedimentation. Fifth, geographic distribution and coordination of each microfossil suite to the paleogeographic setting are necessary to reconstruct the environment.

INTRODUCTION

Interpretations of depositional environments from microfossils are based mainly on comparisons of fossil assemblages to micro-organic remains buried in recent sea bottom sediments. This assumes that the principle of uniformitarianism is operative. If genera or species in a biota are extinct, interpretations are made by comparison of associated fossils to similar modern organic remains. If entire fossil assemblages are extinct, interpretations are based on comparative morphology and associated lithologies.

The principles that apply to microfossils as environment indicators in marine shales are a combination of the basic concepts employed in ecology, sedimentology, and oceanography. The subject is approached here through the following steps: first, an inventory is made of the environmental factors, realms of environment, and kinds of microfossils; second, qualitative data on the occurrence and distribution of microfossils are examined for significant generalizations; and third, quantitative studies are analyzed for important generalizations.

[1] Paper presented at the St. Louis meeting of S.E.P.M., April 26, 1951, as a part of the "Symposium on Paleoecology of Shale and Evaporite Deposition."

ENVIRONMENTAL FACTORS

The complex nature of organic remains in sea bottom muds and fossils in marine sedimentary rocks are controlled by the following factors:

Physical
- Depth of water
- Temperature of water
- Light conditions
- Character of bottom sediments

Movement of water (waves, currents, and turbidity currents)
Distance from shore
Morphology of sea floor
Geographic shape of water body
Geography of adjacent lands

Chemical
Salinity of water
Hydrogen ion concentration
Trace elements
Colloids
Dissolved carbon dioxide
Dissolved oxygen
Nitrogen content
Carbon (organic) content

Biological
Food supply
Associated organisms

A complete picture of the environment could be obtained if all the factors listed could be determined from observations of microfossils in sedimentary rocks. However, many of these factors have not been determined for recent organisms and it is doubtful that some of the factors could ever validly be interpreted for microfossils.

Considerable qualitative and quantitative data are now available for the comparison of micro-organisms with microfossils so as to interpret depth of water, temperature of water, light conditions, character of bottom sediments, salinity of water, hydrogen ion concentration, dissolved carbon dioxide, dissolved oxygen, carbon (organic) content, and associated organisms. Some work has been done on living micro-organisms and their relationship to movement of water, distance from shore, trace elements, colloids, nitrogen content, and food supply. In these categories practically no work on microfossils has been accomplished. Lines of research in these directions should yield fruitful results. The relationships of micro-organisms and microfossils to the morphology of the sea floor, geographic shape of the water bodies, and geography of adjacent lands have been given some attention but work with microfossils requires a great mass of data before interpretations may be made. Geographic relationships are normally a part of any geologic problem but microfossil workers have not emphasized this phase of their science.

Interpretations based on microfossils are important practical items when concerned with depth of water, character of bottom sediments, distance from shore, and geographic shape of the water body. Commercial workers are now expanding their efforts in these directions.

REALMS OF ENVIRONMENT

Marine clays are deposited in various environments ranging from the littoral downward into the abyssal zones. This range is greater than that for any other marine sediment (Kuenen, 1950, p. 314). Marine shales, likewise, may be interpreted as having been deposited in a similar range of environments. The accompanying environment classification from an unpublished chart prepared by the National Research Council Committee on Marine Ecology and Paleoecology is adopted as standard and is reproduced here with the permission of the committee and its chairman, H. S. Ladd (fig. 1).

Special environments such as tidal flats and shallow lagoons are included in the inner neritic and littoral categories. Poorly ventilated (euxinic) basins of varying depths and devoid of benthonic faunas are difficult to place on the classification chart and probably such basins should be added to the standard nomenclature in a special classification.

A comparison of the temperature range charts (fig. 2) with the environment classification chart (fig. 1) emphasizes that organisms living in waters to depths of about 50 meters withstand a wide temperature variation. Organisms living in waters from 50 to 200 meters in depth have a more restricted temperature range and are adapted to moderate temperature variations. Below 200 meters the temperature range is gradually restricted downward to a very narrow belt near an average of 4 degrees centigrade.

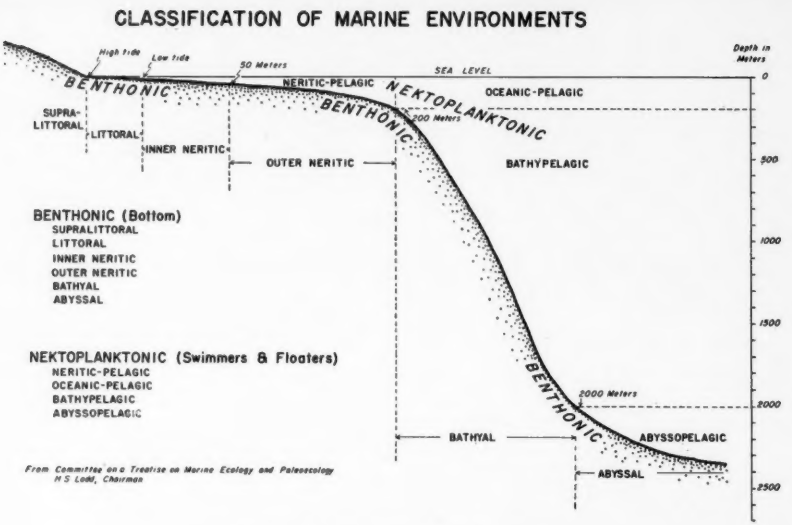


FIG. 1.—Classification of marine environments.

Organisms living in the deeper zones are adjusted to only slight variations and have a remarkably monotonous temperature diet. The wide temperature variation in waters less than 50 meters in depth is related to the depth of sunlight penetration. The maximum depth of light penetration and the maximum depth at which photosynthesis may take place varies for different water bodies. Rough estimates (Parker, 1948; Sverdrup, Johnson, and Fleming, 1942, pp. 774–782) indicate that at least 95 per cent of the light available for photosyn-

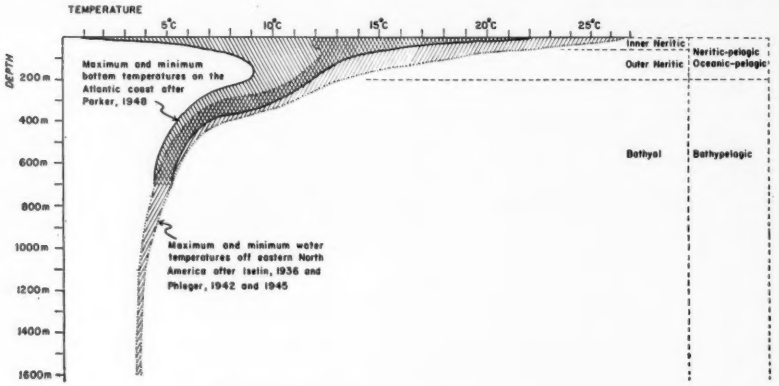


FIG. 2.—Temperature ranges of sea water.

thesis has been absorbed in water 50 meters in depth. Thus, the arbitrary break between the inner neritic and outer neritic zones at the average depth of 50 meters coincides with the change from light to dark and with the change from a zone of wide temperature variation to a restricted temperature zone.

KINDS OF MICROFOSSILS

The chief tools available to micropaleontologists desiring to interpret environments are microfossils and microorganisms. The accompanying list divides microfossils into two groups: first, whole organisms, in which the entire skeleton or test is commonly preserved; and second, embryos, parts, and fragments.

WHOLE ORGANISMS

- Plants or Animals
  - Coccoliths
  - Silicoflagellates
  - Dinoflagellates
  - Discoasterids
- Plants
  - Thallophytes
    - Bacteria
    - Algae
      - Diatoms
      - Charaphytes
    - Fungi
- Animals
  - Protozoa
    - Foraminifers
    - Radiolarians
  - Echinoderms
    - Microblastoids
    - Microcrinoids
  - Bryozoans
  - Arthropods
    - Crustaceans
      - Ostracods
      - Branchiopods
    - Insects
  - Prochordates
    - Graptolites

EMBRYOS, PARTS, AND FRAGMENTS

- Plants
  - Spores and Pollen
  - Seeds
  - Internal structures of woods
- Animals
  - Porifera
    - Sponge spicules
  - Coelenterates
    - Sclerodermites
  - Annelids
    - Worm tubes, setae, castings
    - Scolecodonts
  - Brachiopods
    - Dwarfs and embryos
    - Spines
  - Molluscs
    - Dwarfs and embryos
    - Radulae and otoliths
  - Echinoderms
    - Cystoid, Blastoids, and Crinoid plates and columnals
    - Echinoid plates and spines
    - Asteroid plates
    - Ophuroid ossicles
    - Holothurian parts
  - Arthropods
    - Trilobite dwarfs and embryos
    - Crustacean exoskeleton parts
  - Vertebrates
    - Conodonts
    - Fish teeth, scales and otoliths

Foraminifers have been employed as environment indicators to a greater extent than any other microfossil group because of their widespread geologic and geographic occurrences. Further, qualitative and quantitative studies on modern foraminifers have shown them acutely responsive to their environments. These studies have shown direct relationships between the occurrences of certain genera and species and the limiting environmental factors such as temperature, depth of water, or salinity. These relationships as established in living assemblages are widely applied to interpret similar assemblages in the geologic column.

The use of diatoms, charaphytes, ostracodes, scolecodonts, conodonts, and graptolites as environment indicators has been on a limited basis because the habitats of these groups have not been fully

interpreted. Little work has been accomplished on the dwarfs and embryos of brachiopods, molluscs, and trilobites but future work will undoubtedly coordinate them with the adults. Future work on microblastoids, microcrinoids, and echinoderm fragments should establish these as excellent environment indicators because all are benthonic and thus restricted in their mobility. Bryozoans, like echinoderms, are benthonic and are rapidly being applied with success to environmental problems. The remaining groups on the list are open fields for research because little is known about them now.

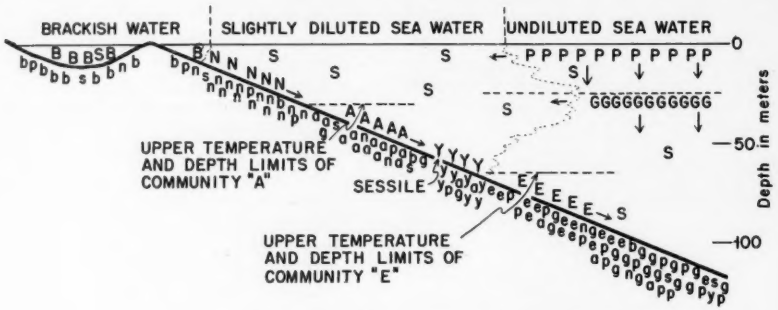


FIG. 3.—Distribution of micro-organisms and their remains.

dead skeletons from corresponding living communities. Greatest concentrations of single community skeletons are in sediments directly beneath the habitat of the living organisms. Brackish water benthonic forms such as "B" are deposited upon death as "b" in brackish water muds. However, various transportation agencies may scatter the skeletons of these brackish water forms on the sea floor slope beyond the realm of the brackish water. Neritic benthonic forms such as "N" are deposited upon death as "n" in neritic muds but may also be scattered by waves, currents, gravity, mud slides, and turbidity currents down the sea floor slope. If the neritic community is living in shallow water some skeletons may be transported by wave action up the slope and into the brackish lagoons. Communities such as "A" and "E" that live below the level of normal wave action supply skeletons "a" and "e" respectively to muds immediately below the communities and to muds down the slopes. With the exception of random scavenger action, skeletons from these communities do not move up the slope. Sessile communities such as "Y" supply skeletons "y" to the sea floor muds in the immediate area of growth. A few skeletons may be unanchored and move down the sea floor slope but this detachment and movement downward is not as prevalent as in unattached forms. The lack

QUALITATIVE STUDIES

Marine micro-organisms live and die within community boundaries. When the organisms die the skeletons are potential microfossils and become part of the debris that will eventually be incorporated in sediment. The distribution of dead skeletons is controlled by the original distribution of the living organisms plus the scattering ability of gravity, wave action, currents, mud slides, turbidity currents, and scavengers.

A theoretical distribution of some micro-organisms and the resulting distribution of dead skeletons is diagramed on figure 3. The large letters represent living communities. The small letters represent sea bottom accumulations of

of mobility of sessile forms suggests they are excellent indicators of depth and temperature of the sea floor.

Planktonic and pelagic communities such as "P" may supply skeletons "p" to any environment but naturally the greatest concentrations will be immediately below the living communities. This concentration may be masked by a prolific benthonic accumulation. Planktonic and pelagic communities such as "G" may live within limited depth ranges below the surface of the sea. These communities shower the sea floor below with skeletons of "g" and like the upper limit of certain benthonic communities are not deposited in muds above the level of the living habitat.

Evidence by Parker (1948) shows that pelagic foraminifers such as *Globigerina* require undiluted sea water to thrive. Where large rivers dilute the coastal waters *Globigerina* do not inhabit the near shore waters and consequently do not supply skeletons to the near shore muds. On the other hand, beach sands of the Fiji islands (Crickmay, Ladd, and Hoffmeister, 1941), are composed of *Globigerina* tests because *Globigerina* live close to shore in water undiluted by large rivers.

Swimmers may supply skeletons "s" to any environment. Swimmers have mobility and distribute their skeletons haphazardly and later the skeletons are subject to all of the agencies of transportation for further scattering on the sea floor.

Two broad generalizations about microfossils are based on the distributions shown on the theoretical diagram in figure 3: first, benthonic microfossils, because of their relative lack of mobility, are the chief indicators of depth, temperature, amount of light, composition of the water, and bottom conditions; second, pelagic, planktonic, and nektonic microfossils with their greater mobility and wider distribution overlap into a variety of sedimentary environments indicating only broad latitudinal boundaries of temperature and salinity. As a corollary to the distribution of microfossils the upper depth and temperature limits are far more important for interpretation of environments than the lower limits because the lower limits are masked by the distribution of skeletons scattered by various transporting agents, especially gravity.

If dead skeletons become particles of the sediments, then microfossils are an integral part of the lithology of sedimentary rocks. Workers in the field of micropaleontology have not consistently tied lithology and fossil occurrences together. The micropaleontological articles in the *Journal of Paleontology* were reviewed from 1940 through 1950 to determine whether the lithology of the host rock was described with the microfossils. The results of this analysis are shown on figure 4. Twenty-three per cent of the papers in these eleven volumes failed to mention lithology. Four of the 17 microfossil papers in the 1950 volume failed to note the lithology of the rocks yielding the described fossils. These facts are important in our particular problem because many of these papers described fossils that may have occurred in shales. It would be impossible to determine from the printed articles what lithology contained the fossils. Such an item of omission is important to future writers and and to future editors.

Depth, temperature, and salinity as related to the distribution of living foraminifers have been the subjects of studies by Norton (1930), Natland (1933), Phleger (1942, 1948), Phleger and Hamilton (1946), Phleger and Walton (1950), Parker (1948), Lowman (1949), and Said (1950). These workers have shown certain patterns of occurrences among foraminifers based on samples gathered from the sea floor. Figure 5 shows a simple application of the knowledge of modern Foraminifera distribution as applied to a detailed study of the Marquez shale of the lower Claiborne, Eocene, of the Gulf Coastal Plain of Texas. The interpretation of the environ-

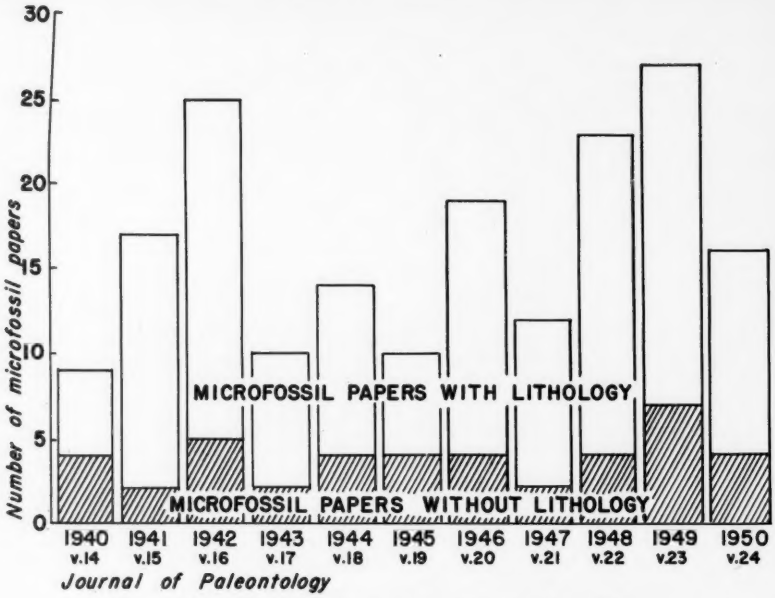


FIG. 4.—Tabulation of microfossil papers with and without lithology.

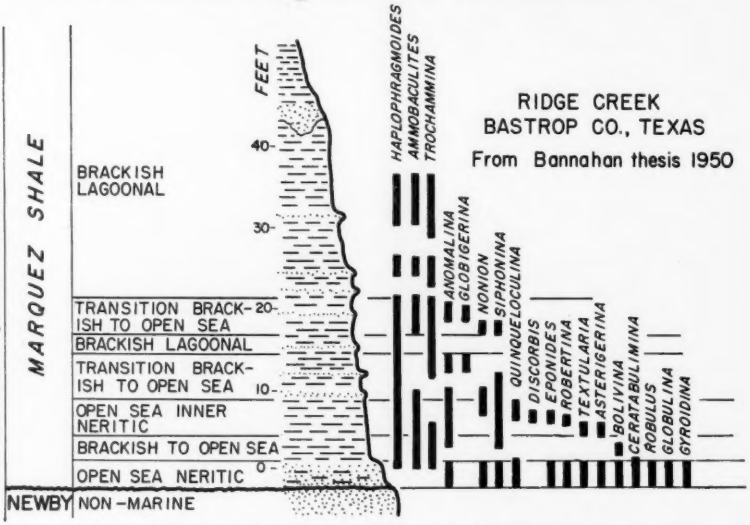


FIG. 5.—Qualitative paleoecology analysis of Marquez shale (from Bannahan, 1950, unpublished Master's thesis, University of Texas).

mental conditions is based wholly on the qualitative distribution of kinds of foraminifers. The distribution chart is made so that genera indicating deeper water are plotted on the right side. This arrangement not only emphasizes the paleoecologic conditions but is also useful in detailed stratigraphic correlations.

Qualitative microfossil data have greater value for interpretative purposes if the data are assembled with geographic relationships. The emphasis on geography and paleogeography is seldom made a part of micropaleontological studies. Figure 6 is an example showing the paleogeographic setting of the Woodford black shale which contains abundant conodonts and spores. The evidence supporting the interpretation that the Woodford shale may have been deposited in relatively deep stagnant waters is more convincing in the light of the paleogeographic studies (Ellison, 1950, p. 16).

QUANTITATIVE STUDIES

A mathematical approach to environment interpretations by quantitative micropopulation studies, although tedious and slow, promises to be the firmest basis for paleoecological investigations. If it is assumed that microfossils are particles of sediments and integral units of sedimentary rocks, then, the mathematical approach will be along the same lines now being employed for sedimentary analysis. Composition, quantity, and particle size, shape, and arrangement are the factors commonly determined for sediments and likewise may be determined for microfossils. Composition as applied to microfossils may mean species, genus, family, or ecological group. Composition, in some cases, may indicate shape. For example, to mention globigerinids and fusulinids would give a definite impression of shapes. Microfossil size studies may be made by screening in the same fashion that ordinary sediments may be screened. Arrangement of microfossils may be studied with polished sections and thin-sections in the same way that sedimentary fabrics are studied.

Probably the most significant factor to be determined is the quantity of microfossils or micro-organisms. Population counts have not been on a standardized uniform basis and as a result most of the data can not be correlated. Most workers have estimated numbers on a semi-quantitative basis where each worker defines his own limits for the terms very rare, rare, common, abundant, and very abundant. The limits may be related to a specific volume of original rock, a specific weight of original rock, a specific volume of concentrated fossil residue, a specific weight of concentrated fossil residue, or merely a percentage relationship of a random collection of specimens.

The following investigators have made quantitative microfossil and micro-organism studies; Norton (1930), Natland (1933), Schott (1935), Brotzen (1936), Phleger (1942, 1948), Phleger and Hamilton (1946), Phleger and Walton (1950), Tromp (1939, 1940, 1941, 1943, 1949), Tromp and Tasman (1942), Hoglund (1947), Parker (1948), Morischima (1948), Oinomikado and Stach (1948), Renz (1948), Isrealsky (1949), Lowman (1949), and Said (1950). Said's (1950) review of the literature indicates that the most significant development is Schott's suggestion of a standard term "foraminiferal number." This term is defined as the number of foraminifera contained in 1 gram of dry original sediment or rock. Said (1950, p. 14) expands this term by suggesting that there should be a "pelagic number" and a "benthonic number." Such standardized numbers would be extremely useful in the quantitative comparison of micropopulations. There are, however, other microfossils and micro-organisms in addition to foraminifers and it is proposed here that the standard terms "microorganism number" and "microfossil number" be employed to mean the number of micro-organisms or microfossils in 1 gram of dry original sediment or rock respectively. The proposed term "microfossil number" will give a true measure of

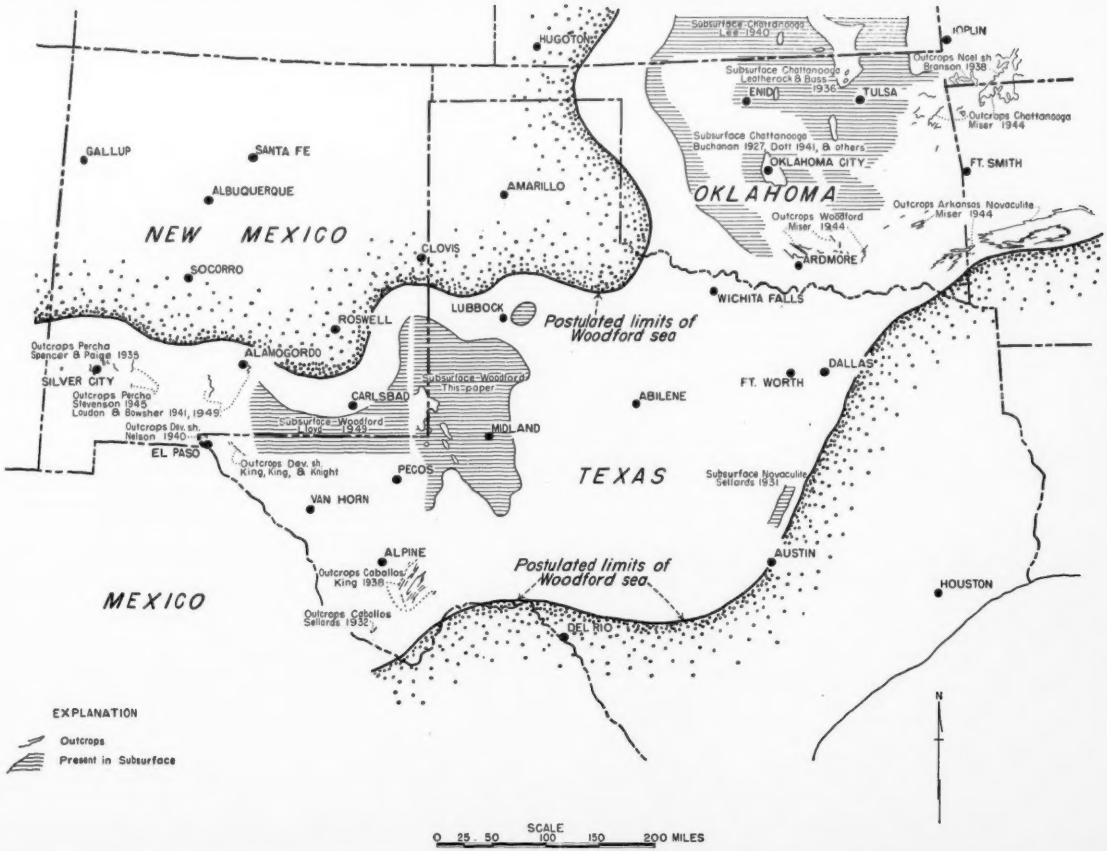


FIG. 6.—Woodford paleogeography (reproduced by courtesy of the University of Texas Bureau of Economic Geology).

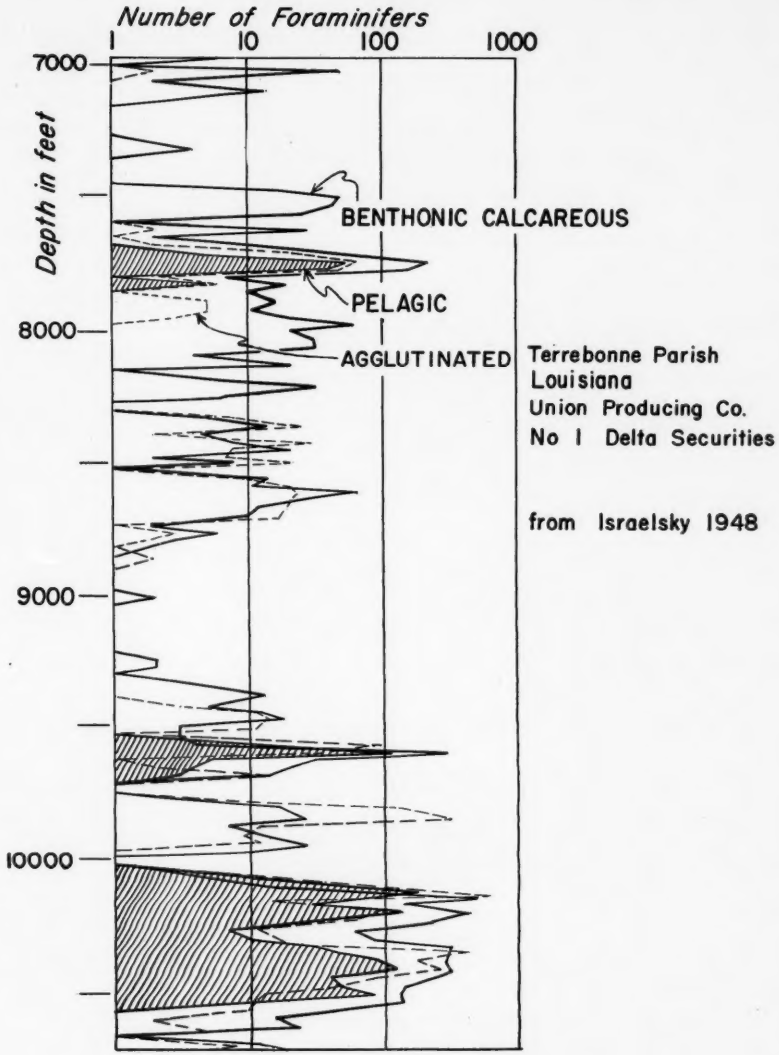


FIG. 7.—Quantitative micropopulation analysis.

abundancy and may be converted to percentage relationships. Random percentage counts cannot, however, be converted to microfossil numbers unless the percentage counts are based on a definite amount of original host rock.

The usefulness of "microfossil numbers" is not fully understood yet because accumulation of data is laborious and the amount of data available is meager. However, in a preliminary survey the idea of micropopulation studies seems to be readily applicable to practical stratigraphic correlations. Figure 7 is a chart showing micropopulation counts taken directly from Israelsky's (1949) classical quantitative study. The actual counts are used here as if they were "microfossil numbers." There are several distinct zones in the geological column of the well examined by Israelsky and it is probable that such curves can be duplicated in adjacent wells. Correlation of these curves may be compared to correlation of electric logs and radioactive logs.

Amato (1950) in an unpublished Master's thesis directed by Benjamin Burma at the University of Nebraska applied Israelsky's methods to a well adjacent to the well analyzed by Israelsky. The results showed a definite correlation between the two wells. Actual counts were not recorded in Amato's thesis and, therefore, a condensed chart similar to figure 7 was not constructed from Amato's work. Both Israelsky and Amato indicate that considerable time is consumed in making the population counts and it is clear that the method will become more useful only after shorter methods of counting are devised.

REFERENCES

AMATO, F. L., *1949*. The oscillation chart as method of correlation: Unpublished Master's thesis, University of Nebraska.

BANNAHAN, A., *1950*. The Foraminifera of the Marquez (Middle Eocene) shale, Bastrop County, Texas: Unpublished Master's thesis, University of Texas.

BROTZEN, F., *1936*. Foraminiferen aus dem Schwedischen Untersten senon von Eriksdal in Schonen: *Sveriges geologiska undersokning*, ser. C no. 396, pp. 5–29.

CRICKMAY, G. W., LADD, H. S., and HOFFMEISTER, J. E., *1941*. Shallow water Globigerina sediments: *Geol. Soc. America Bull.*, vol. 52, pp. 79–106.

ELLISON, S. P., JR., *1950*. Subsurface Woodford black shale, west Texas and southeast New Mexico: *Univ. Texas Bur. Econ. Geol. Rept. Inv.* 7, pp. 1–20.

HOGLUND, H., *1947*. Foraminifera of the Gullmar Fjord and Skagerak: *Zool. Bidrag. fran Uppsala*, Bd. 26, pp. 203–212.

ISRAELSKY, M. C., *1949*. Oscillation Chart: *Am. Assoc. Petroleum Geologists Bull.* vol. 33, pp. 92–98.

KUENEN, PH. H., *1950*. *Marine Geology*, John Wiley and Sons New York: pp. 302–362.

LOWMAN, S. W., *1949*. Sedimentary Facies in Gulf Coast: *Am. Assoc. Petroleum Geologists Bull.* vol. 33, pp. 1939–1997.

MORISCHIMA, M., *1948*. Foraminifera thanatocoenoses of Ago Bay, Kii peninsula, Japan: Rep. Comm. Marine Ecol. and Paleoecol., *Nat. Research Council Bull.* 8, pp. 111–117.

NATLAND, M. L., *1933*. The temperature and depth distribution of some recent and fossil Foraminifera in the Southern California region: *Scripps Inst. Oceanography Bull.*, vol. 3, no. 10, pp. 225–230.

NORTON, R. D., *1930*. Ecologic relations of some Foraminifera: *Scripps Inst. Oceanography Bull., Tech.* ser. vol. 2, no. 9, pp. 331–388.

OINOMIKADO, T., and STACH, L. W., *1948*. Recent shallow water Foraminifera assemblage from Nugata prefecture, Japan: Rep. Comm. Marine Ecol. and Paleoecol., *Nat. Research Council Bull.* 8, pp. 104–110.

PARKER, F. L., *1948*. Foraminifera of the Continental Shelf from the Gulf of Main to Maryland: *Harvard Coll. Mus. Comp. Zoology Bull.*, vol. 100, no. 2, pp. 213–241.

PHLEGER, F. B., 1942. Foraminifera of submarine cores from the continental slope: *Geol. Soc. America Bull.*, vol. 53, pp. 1073–1098.

PHLEGER, F. B., *1948*. Foraminifera of a submarine core from the Caribbean sea: *Goteb. vet. Vitt. Samh. Hdl.*, ser. B 5, n. 14, pp. 1–9.

PHLEGER, F. B., and HAMILTON, W. A., *1946*. Foraminifera of two submarine cores from the North Atlantic basin: *Geol. Soc. America Bull.*, vol. 57, pp. 951–966.

PHLEGER, F. B., and WALTON, W. R., *1950*. Ecology of marsh and bay Foraminifera, Barnstable, Massachusetts: *Am. Jour. Sci.*, vol. 248, pp. 274–294.

RENZ, H. H., *1948*. Stratigraphy and fauna of the Agua Salada group, state of Falcon, Venezuela: *Geol. Soc. America Mem.* 32, pp. 1–111.

SAID, R., *1950*. The distribution of Foraminifera in the northern Red Sea: *Cushman Lab. Foram. Research Contr.*, vol. 1, no. 3, pp. 9–29.

SCHOTT, W., *1935*. Die Foraminiferen in dem aequatorialen teil des Atlantischen Ozeans: *Deutsche Atlantische Exped. Meteor 1925–1927*, Bd. III teil 3 pp. 43–134.

SVERDRUP, H. U., JOHNSON, M. W., and FLEMING, R. H., *1942*. *The Oceans:* New York, Prentice-Hall, pp. 1–1087.

TROMP, S. W., *1939*. The value of generic determination in microstratigraphy: *Geologie an Mijnbouw*, Holland, Aug. no. 8, pp. 202–204.

TROMP, S. W., *1940*. The value of quantitative data in microstratigraphy: *Jour. Paleontology*, vol. 14, pp. 379–381.

TROMP, S. W., *1941*. Preliminary compilation of the stratigraphy, structural features and oil possibilities of southeast Turkey and a comparison with neighboring areas: *Maden Telkick ve Arama Publ. Ankara*, ser. A, no. 4, pp. 20–23.

TROMP, S. W., *1943*. Microfaunae of the upper Cretaceous and Tertiary sections (Arabian facies) in the Urfa and Gasiantep regions (southern Turkey): *Maden Telkick ve Arama Publ. Ankara*, sena 8, sayi 1/29, pp. 134–141.

TROMP, S. W., *1949*. The value of Globigerinidae ratios in stratigraphy: *Jour. Paleontology*, vol. 23, pp. 223–224.

TROMP, S. W., *1949*. The determination of the Cretaceous-Eocene boundary by means of quantitative generic microfaunal determinations and the conception of "Danian" in the near east: *Jour. Paleontology*, vol. 23, pp. 673–676.

TROMP, S. W., and MEHLIKA TASMAN, *1942*. The microfaunae of the basal Eocene and upper Cretaceous section of the Ramandag well No. 2 (southeast Turkey): *Maden Telkick ve Arama Publ. Ankara*, sene 7, sayi 1/26, pp. 121–125; sene 8, sayi 1/29, pp. 251–253.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 226–232
DECEMBER, 1951

THE DEPOSITIONAL ENVIRONMENT OF RED AND GREEN SHALES[1]

RALPH E. GRIM
University of Illinois, Urbana, Illinois

ABSTRACT

Mineralogical analyses of a series of Paleozoic shales from Illinois show that illite and chlorite are present in all of them with the former the dominant component. Kaolinite is sometimes present in minor amounts. A review of the literature, regarding the occurrence of the clay minerals and an analysis of the general environmental conditions favorable for the formation of the various clay minerals, indicates that marine shales are likely to be composed of the mica clay minerals, sometimes with minor amounts of kaolinite, and that nonmarine shales are likely to have kaolinite as a prominent component with lesser amounts of the three-layer clay minerals.

The probable diagenetic changes in marine argillaceous sediments are discussed, and it is suggested that there are two stages of such changes; namely, a rapid development of well crystallized mica from "degraded illite" and "degraded chlorite" taking place about as rapidly as such material is brought to the sea, and a slow gradual change of montmorillonite and kaolinite to the micas. The relation of these changes to variations in the environment, in the source material, and rate of accumulation are considered.

INTRODUCTION

Clay mineral studies have reached the point where some generalities regarding the occurrence of particular clay minerals in argillaceous sediments of various types and modes of origin can be made. These investigations, together with studies of the synthesis of clay minerals and their origin in soils, have indicated, in a general way, the environmental conditions under which the various clay minerals are stable. It is proposed herein to consider the implications of the generalities derived from such studies on the depositional environment of argillaceous sediments, particularly red and green shales.

No attempt will be made to define "shale" as it is not essential to these remarks. Some consideration, however, will be given to the clay mineral composition of sediments other than those which would be classed as shales, since that is necessary for an understanding of the matter at hand.

[1] Paper presented at the St. Louis meeting of S.E.P.M., April 26, 1951, as a part of the "Symposium on Paleoecology of Shale and Evaporite Deposition."

CLAY MINERAL COMPOSITION OF THE PALEOZOIC SHALES OF ILLINOIS

The writer, with W. F. Bradley and W. A. White, former colleagues on the Illinois Geological Survey, have for many years studied the composition of the Paleozoic shales in Illinois. This work has shown that the dominant clay mineral in all of these shales is illite. A chloritic clay mineral is present in almost all of them, usually in relatively small amounts. Kaolinite is frequently, perhaps usually, completely absent, and when present at all, it is not abundant. It is important that kaolinite is most common and most abundant in shales of late Mississippian and early Pennsylvanian age. None of these shales, in an unweathered state, contain substantial amounts of montmorillonite or of the attapulgite-sepiolite clay minerals.

Quartz is a frequent component—sometimes in considerable abundance. The shales vary in color from red to green, gray, and black. Some of them are calcareous and some have abundant sideritic concretions.

CLAY MINERAL COMPOSITION OF THE PENNSYLVANIAN UNDERCLAYS OF ILLINOIS

Grim and Allen (1938) have shown that the so-called underclays, occurring beneath the lowermost Pennsylvanian coals in Illinois, are largely composed of kaolinite. The underclays beneath higher coals are composed of illite without any kaolinite. It is important that in the Pennsylvanian section in Illinois where the shales contain appreciable kaolinite, the underclays are composed of kaolinite, but where the underclays are illitic, the shales contain substantially no kaolinite.

The illitic underclays are generally calcareous. The writer knows of no calcareous underclay that is kaolinitic. It appears that the composition of the underclays has not undergone substantial change since their accumulation. In some of the illitic underclays, the uppermost part directly beneath the coals has been leached of its carbonate without any appreciable change in the clay mineral composition.

GENERAL CONCLUSIONS REGARDING THE OCCURRENCE OF CLAY MINERALS IN SEDIMENTS

In a very important recent work, Millot (1949) has published clay mineral analyses for a large number of samples of sediments whose origin is well established on the basis of paleontologic or stratigraphic evidence. He shows that in marine sediments, illite is the dominant clay mineral; if the sediments are calcareous, kaolinite is generally absent; if noncalcareous, kaolinite is sometimes present in minor amounts; chlorite and hydrobiotite are usually present in minor amounts; montmorillonite is generally absent. In sediments of lagoonal origin, illite is usually the dominant clay mineral; montmorillonite or attapulgite-sepiolite is occasionally the dominant component; hydrobiotite and chlorite are common but always of minor importance; kaolinite is usually absent and never makes up more than about 30 per cent of the sediment. In aggressive[2] lacustrine sediments, kaolinite is the dominant component; illite is frequently absent and never makes up more than 30 per cent of the total; other clay minerals, except attapulgite-sepiolite, may be present in minor amounts. In calcareous lacustrine sediments, illite appears to be the dominant component.

Grim, Lamar and Bradley (1937) have shown that illite is generally the dominant component of any clay present in the limestones and dolomites in Illinois. Kaolinite is usually completely absent or only a minor component but, in a few samples it was the dominant clay mineral. Montmorillonite was generally not observed, but it is now known that the techniques available at the time these studies were made would not have revealed small amounts of this mineral.

The clay minerals in the coals of Illinois, England, and Germany, have been studied by Ball (1934), Hicks and Nagelschmidt (1943), and Endell and Endell (1943). In each case, kaolinite is the dominant clay mineral component and frequently the only one present.

The writer has made clay mineral analyses of several hundred miscellaneous samples of a large variety of argillaceous sediments from all over the world. Out of this work have come the following conclusions which are believed to be based on sufficient analyses to have general significance.

a) Samples called shales, because of their laminated character and hardness, are usually largely composed of illite; chloritic mica is usually present; kaolinite is usually absent; montmorillonite is usually absent. In kaolinitic sediments, any lamination is usually due to the presence of thin beds of varying composition rather than to an aggregate orientation of particles, e.g., flake-shaped units.

b) Kaolinite is generally absent in

[2] Millot classifies as "aggressive," a lacustrine environment in which the water is fresh and movement is adequate to carry away alkalies and alkaline earths.

marine sediments and in calcareous sediments.

c) There is very little montmorillonite in sediments older than the Mesozoic. The writer knows of no thick sediments, like the Pierre shale (Upper Cretaceous) and Porters Creek (Eocene), which are rich in montmorillonite in the older sediments. Some thin beds of montmorillonite are known in these older sediments. For example, there are thin streaks of montmorillonite in the Ordovician limestones of northern Illinois.

d) Calcareous or dolomitic sediments are likely to contain illite, and/or montmorillonite. The latter component is particularly evident in younger formations.

CLAY MINERAL COMPOSITION OF RECENT SEDIMENTS

Much remains to be learned about the clay mineral composition of Recent sediments. Some data are available, however, based on the work of Correns (1937), Dietz (1941), Grim, Bradley and Dietz (1949), and others (Leinz, 1937, Revelle, 1936). In Recent marine sediments illite appears to be universally present and almost always the dominant component. Kaolinite, montmorillonite and chlorite are probably usually present also, but in minor amounts. Occasionally, probably because of local variations such as nearness to a particular source, kaolinite or montmorillonite is the major component. There is a suggestion, based primarily on the work of Leinz (1937) that kaolinite is relatively less abundant in highly calcareous sediments, e.g. globigerina ooze. Neither Correns (1938) nor Grim, Bradley and Dietz (1949) found any appreciable vertical variation in the composition of the core samples they studied. Nevertheless, Dietz (1941) presents definite evidence that illite is forming in Recent marine sediments, and Grim, Bradley, and Dietz (1949) suggest that illite and chlorite are being formed and that kaolinite is being lost in at least some of the samples studied by them.

Too little information is available on Recent non-marine sediments to permit very trustworthy generalizations. It appears, however, that all types of clay minerals may be present, except that in calcareous material, kaolinite is absent or relatively unimportant and in highly alkaline desert sediments, the attapulgite-sepiolite clay minerals are likely to prevail.

COMPARISON OF THE CHARACTER OF RECENT AND ANCIENT SEDIMENTS

Again the analytical data are not adequate for positive generalizations but the following conclusions seem to be warranted.

There is relatively less montmorillonite in ancient sediments, suggesting that montmorillonite must, therefore, be changed to some other clay mineral, at least under some conditions of diagenesis or later processes. Kaolinite is relatively less abundant in ancient marine sediments and it also must frequently undergo a change to some other clay mineral in the marine environment or later.

Illite and the chloritic clay minerals are even more abundant in ancient sediments than in Recent sediments, particularly in those of marine origin; hence these clay minerals must form sometime during diagenesis or later.

Ancient sediments frequently are harder than Recent sediments even though their clay mineral composition may be exactly the same. Also an aggregate parallel orientation of clay mineral components seems to be more common in ancient sediments.

STABILITY CONDITIONS OF THE CLAY MINERALS

Studies of the synthesis of the clay minerals in the laboratory, particularly by Noll (1935), and of the genesis of the clay minerals in soils by many investigators, have suggested the following generalities:

Kaolinite is favored by an environment of low pH, where leaching is active and alkalies or alkaline earths are either absent or removed as rapidly as they are

liberated from the primary minerals. The presence of calcium retards or hinders the formation of this clay mineral.

Illite is favored by an alkaline environment and the presence of potash.

Montmorillonite is favored by an alkaline environment and the presence of magnesium. Indeed, some magnesium seems to be essential for the existence of this clay mineral.

Chlorite also requires an alkaline environment and magnesia. Probably the requirement of magnesium is higher for chlorite than for montmorillonite. In general, the three-layer clay minerals are favored by alkaline conditions and in such an environment the character of the alkali or alkaline earth is a dominating factor.

The sepiolite-attapulgite-palygorskite clay minerals seem to be favored by a very high pH and the very high content of alkalies and alkaline earth found in dry desert basins.

DIAGENETIC AND LATER CHANGES UNDER MARINE CONDITIONS

The marine environment is an alkaline one in which no leaching takes place and the water contains considerable dissolved calcium. It, therefore, favors the persistence or formation of illite, chlorite and montmorillonite. Kaolinite should not form and perhaps would not persist if formed.

Land derived debris carried to the sea must consist of all types of clay minerals with the relative abundance of particular clay minerals varying, depending on the conditions in the source area. Any large area of accumulation, fed by a source area of some size and diversity of climate and topography, would probably receive material containing all types of clay minerals. It seems certain that a major part of the mud carried to the sea in many areas is degraded illite or chlorite. The degraded minerals represent material that has been somewhat leached of its constituent alkalies or alkaline earths in weathering processes, but not sufficiently to transform it into new minerals. In the case of degraded illite, only some of the K^+ has been leached from between the silicate unit layer. Such degraded minerals would have structural deficiencies for alkalies and alkaline earths and would quickly adsorb any available K^+ or Mg^{++}, with attendant increase in the perfection of the mica structure. It seems likely that such reconstitution of the micas is a most important diagenetic process. It should take place about contemporaneously with accumulation and would not, therefore, be reflected in any vertical change in composition of core samples. It would serve continuously to keep down the composition of K^+ and Mg^{++} in the marine environment.

It seems certain that chloritic mica and illite also form from other minerals during marine diagenesis. Thus illite, and possibly chlorite, probably form from montmorillonite and possibly from kaolinite. It seems likely that such diagenetic changes are very slow, and from the occurrences of kaolinite and montmorillonite in some ancient sediments, it is obvious that the changes may never occur, or at least never be completed. Little can be speculated on the factors that influence the rate of these slow changes or their failure to occur at all in some instances. Undoubtedly the rate of accumulation with the relative abundance of K^+ and Mg^{++} must be important; the nature of the source material, possibly poorly crystallized kaolinite, is more susceptible than well crystallized kaolinite; the oxidizing or reducing nature of the environment may be significant, but as yet there is no definite indication one way or the other for the importance of this factor; and the presence and character of organic material may be of significance but again the possible influence is not clear.

The change from montmorillonite to illite or chlorite is a very simple one structurally. A montmorillonite with K^+ or Mg^{++} as the adsorbed ions, on drying under some conditions will have characteristics like illite or chlorite respectively. Thus, much of the montmorillo-

nite in recent sediments, on compaction and dehydration and the consequent removal of the adsorbed water from between the unit silicate sheets, will be transformed into an illite or a chlorite depending on the ion present. Much of the illite and chlorite in ancient sediments was probably formed in this way, after the sediment was removed from the environment during drying and compaction. Montmorillonite would persist until substantially complete loss of adsorbed water. Since the mineral transformations and compaction are going on simultaneously, the resulting product would probably show an aggregate orientation of the clay minerals. Degree of parallel orientation in relatively nonmetamorphosed sediments may be a measure of the amount of this mineral alteration during compaction.

The hardness or slakability of sediments is to a considerable extent dependent on the adsorbed water between the clay mineral particles. As the water film is removed, the attraction between particles due to van der Waals and ionic forces becomes more powerful. When the clay minerals lose substantially all of their adsorbed water, they either will not rehydrate at all or only with considerable difficulty. The changes outlined, therefore, as taking place during compaction would be accompanied by a hardening of the material and a loss of slakability.

The nature of the marine environment and diagenetic changes in it are such, that variations in the character of the source material *might be* reflected in the sedimentary accumulation. For example, a kaolinitic marine sediment means a kaolinitic source. Also, it means a relatively rapid accumulation with the persistence of kaolinite through an environment fundamentally unfavorable for it. A completely micaceous marine sediment means a source area producing little kaolinite and/or extremely slow accumulation. It seems likely that source material containing a considerable amount of kaolinite would yield a marine sediment in which at least some kaolinite persisted unless deposition was very slow.

Glauconite

Glauconite is a member of the illite group of clay minerals that has certain rather unique characteristics and is generally believed to form during marine diagenesis. Many investigators have recorded the frequent association of glauconite and organic residues and it has been generally concluded that the presence of organic material is necessary for its formation.

Galliher (1935) has shown that some glauconite has formed as an alteration product of biotite with the alterations taking place under reducing conditions and slow deposition. Unless deposition is slow, so that alteration takes place before burial, the biotite persists. Hendricks and Ross (1941) have reviewed the literature which shows that minerals, other than biotite, may alter to glauconite in a marine environment.

Hadding (1932) showed that glauconite occurs as flakes and as pigmentary material, in addition to the well known large rounded pellets. According to Hadding, glauconite forms in the shallow sea in agitated water which is not highly oxygenated. It forms during times of decreased accumulation of sediment and often during negative sedimentation. Revelle (1936) also has emphasized that glauconite is currently forming off coasts lacking important rivers where deposition is slow. Hendricks and Ross (1941) conclude that the mineral is formed in a reducing environment maintained by bacterial action—the environment probably remaining unchanged for long intervals of time. The very uniform content of magnesium and the rather constant ratio of Fe^{+++} to Fe^{++} indicate that a critical content of magnesium and a particular oxidation-reduction potential might be required for glauconite to form. The ratio of Na^{+} to K^{+} in glauconites is rather distinctive, suggesting that a certain concentration of these ions is also required.

DIAGENETIC CHANGES UNDER NON-MARINE CONDITIONS

Almost no data are available on this subject, but it would seem likely that there would be little diagenetic change as a general thing. Under conditions where there was a paucity of alkalies and alkaline earths, kaolinite would be the stable form. In an environment where there is aggressive water, e.g., in certain lakes, kaolinite may actually form from the three layer minerals after accumulation. If water movement is so sluggish that alkalies and alkaline earths tend to increase in concentration, then illite, chlorite, or montmorillonite may form, depending on the particular cations that are prevalent. If the salt concentration is very high, as for example in salt pans, the sepiolite-attapulgite-palygorskite minerals may result.

COLOR OF ARGILLACEOUS SEDIMENTS

The color of argillaceous sediments is a large subject on which much has been written. It is desired to consider here only a few points that follow from the foregoing discussion.

A red or green argillaceous sediment means the absence of appreciable organic material. Kaolinite is colorless; chlorite is green; illite is green, yellow, or black; as far as the writer knows, no red illite has been found. Montmorillonite may be white, yellow, red, green, or gray, depending on its composition.

In the author's experience, red argillaceous sediments, except in rare cases, are red because of pigmentary red iron oxide or hydroxide, rather than because of the clay mineral component. This is probably true also for yellow sediments, but to a lesser extent. A red color, therefore, is due to a supply of ferric iron oxide or hydroxide from the source area, and probably to an oxidizing environment preserving the higher state of oxidation; or, red color may be due to vigorous oxidizing conditions tending to oxidize any nonferric iron added to the environment, and to liberate ferric iron from the structures of the iron-bearing silicates. In any case, red or yellow color probably means oxidizing conditions. One can conceive, however, of an area of rapid accumulation having very mild reducing conditions, in which yellow or red material might be present because of rapid burial. It seems likely that ferric iron would tend to resist incorporation in the lattice of clay minerals developed during diagenesis more than ferrous iron, i.e. red sediments would tend to stay red.

Under reducing conditions whereby the iron was changed to the ferrous state, one might expect that the iron would be incorporated either in the clay minerals or perhaps in carbonates—in any case the color would not be red, but perhaps green, gray or even black. Green color, however, does not necessarily mean a reducing environment on the basis of present data, since the chlorite clay mineral is green, and there is no reason to believe it requires a reducing environment for its formation.

In general, the color probably depends on whether oxidizing or reducing conditions prevail, and on the source material. In an aqueous environment, conditions may vary from oxidizing to reducing, depending on the topography of the bottom, water movement, rate of sedimentation, presence of organic material, and possibly other factors. The cause and effect of these factors on oxidation and color is complicated. This is illustrated by the genesis of glauconite which accumulates under conditions of slow or negative sedimentation and a general environment suggesting oxidation whereas the environment actually is probably reducing, perhaps because of bacterial action as suggested by Hendricks and Ross (1941).

REFERENCES

BALL, C., *1934*. Kaolinite in Illinois coal: *Econ. Geology*, vol. 29, pp. 767–776.

BRAMLETTE, M. M., and BRADLEY, W. H., *1940*. Geology and biology of North Atlantic deep

sea cores between Newfoundland and Ireland: *U. S. Geol. Survey Prof. Paper 196*, Part I, 34 pp.

CORRENS, C. W., *1937*. Die Sedimente des aquatorialen Atlantichen Ozeans: *Deutsche Atlantische Exped. Meteor 1925–27, Wiss. Erg.* Bd. III, Teil. 3, 298 pp.

CORRENS, C. W., *1938*. Zur Frage der Neubildung von Glimmer in jungen Sedimenten: *Geol. Rundschau*, vol. 29, pp. 220–222.

DIETZ, R. S., *1941*. Clay minerals in Recent marine sediments: Unpublished Ph.D. thesis, University of Illinois.

ENDELL, J., and ENDELL, K., *1943*. Über die Bestimmung der Rontgenfeinstruktur mineralischer Bestandteile von Kohlen und Aschen sowie ihre technische Bedeutung: *Feuerungstechnik.*, vol. 31, pp. 137–143.

GALLIHER, E. W., *1935*. Glauconite genesis: *Geol. Soc. America Bull.*, vol. 46, pp. 1351–1365.

GRIM, R. E., and ALLEN, V. T., *1938*. Petrology of the Pennsylvanian underclays of Illinois: *Geol. Soc. America Bull.*, vol. 49, pp. 1485–1513.

GRIM, R. E., BRADLEY, W. F., and DIETZ, R. S., *1949*. Clay mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California: *Geol. Soc. America Bull.*, vol. 60, pp. 1785–1805.

GRIM, R. E., LAMAR, J. E. and BRADLEY, W. F., *1937*. The clay minerals in Illinois limestones and dolomites: *Jour. Geology*, vol. 45, pp. 829–843.

HADDING, A., *1932*. The Pre-Quaternary sedimentary rocks of Sweden. IV. Glauconite and glauconitic rocks: *Medd. Lunds. Geol. Mineral. Institute*, vol. 51.

HICKS, D. and NAGELSCHMIDT, G., *1943*. The chemical and x-ray diffraction analysis of the roof and clod of some south Wales seams, and of the mineral matter in coal: *Medical Research Council of Great Britain, Special Rept.* ser no. 244, 30 pp.

HENDRICKS, S. B., and ROSS, C. S., *1941*. Chemical composition and genesis of glauconite and celadonite: *Am. Mineralogist*, vol. 26, pp. 683–708.

LEINZ, V., *1937*. Die Mineralfazies der Sedimente des Guinia Beckens: *Deutsche Atlantische Exped. Meteor*, Bd. III, Tiel. 3, pp. 245–262.

MILLOT, G., *1949*. Relations entre la Constitution et la Genèse des Roches Sédimentaires Argileuses *Géologie Appliquée et Prospection Minière:* Univ. of Nancy, vol. II, no. 2, 3, 4, 352 pp.

NOLL, W., *1935*. Mineralbildung im System Al_2O_3-SiO_2-H_2O: *Neues Jahrb. f. Min. Beil.*, Bd. 70, Abt. A., pp. 65–115.

REVELLE, ROGER, *1936*. Marine bottom samples collected in the Pacific Ocean by the *Carnegie* on its seventh cruise: Unpublished Ph.D. thesis, University of California.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 233–237
DECEMBER, 1951

THE RELATIONSHIP OF THE BIOTIC AND LITHIC FACIES IN RECENT GULF COAST SEDIMENTATION[1]

SHEPARD W. LOWMAN
Rensselaer Polytechnic Institute, Troy, New York

ABSTRACT

The structural setting of Gulf of Mexico sedimentation is outlined against a backdrop of Tertiary stratigraphy. Regional biotic and lithic facies are described and examples of typical interrelationships are given. Some possible applications are suggested.

INTRODUCTION

Ten years ago it probably would have seemed odd to introduce a paper on Recent sediments with references to Tertiary structural history. Today it probably seems commonplace—and properly so.

There is a very close correlation between the present sediments of the northern Gulf of Mexico and the sedimentary tectonic history of the late Tertiary. So much so that it is hard to see how we could interpret one without the other.

To begin with, the Recent and Tertiary sediments have strikingly similar patterns of distribution in the northern Gulf of Mexico region. Both are predominately sandstone and shale in the west, and limestone in the east. In both of them the major facies divisions are distributed in broad bands roughly parallel to the present coast. Facies criteria can be developed in the Recent and applied to the Tertiary. This is the contribution of the Recent to the over-all picture.

The Tertiary on the other hand gives information on the behavior of the facies in depth. All stratigraphic units in the Tertiary thicken in a seaward direction. There is gradual thickening of each major unit from continental deposits to shore-line deposits to shallow marine deposits and so on.

Such a sedimentary history indicates that the continuously subsiding Continental Shelf has been built up and maintained at wave base by an inflow of sediments. There is no hint of a wave-cut shelf such as is postulated for some areas.

The form of the present Shelf fits this hypothesis very well. This floor is relatively flat and gently sloping. It is marked by raised ridges, knobs, banks and shoals of sediment, all of which add to the impression that it is a constructional feature rather than a wave-cut bench. The subdued canyon off eastern Louisiana with its landward end filled with sediment contributes further to the same impression.

Sedimentation in the northwestern Gulf region apparently proceeds by a rapid alternation of deposition, erosion, transportation, and deposition again, as storm waves pick up fine sediment, transport it and redeposit it farther seaward. (Many bays and lagoons are floored with mud and silt; their depth is proportional to their width, because the width controls the size of the waves, and the waves control the depth.) It appears probable that in periods of calm, the curing of the sediments would begin again in the uppermost realm of diagenesis, only to be interrupted by another storm. Gradually, as the bottom sinks, the sediments would be buried to a depth

[1] Paper presented at the St. Louis meeting of S.E.P.M., April 26, 1951, as a part of the "Symposium on Paleoecology of Shale and Evaporite Deposition."

at which they no longer would be reached by storm-wave erosion. In this way fine sediment could be deposited at wave base. It can be deposited above wave base, as in the case of the bird-foot delta of the Mississippi which has built a pier of mud and silt 60 miles seaward in a few hundred years, right into the teeth of Gulf Coast hurricanes. Enough material is being brought to the Delta by the river to repair the damage and build new portions of the delta each decade.

CYCLICAL PATTERNS IN THE TERTIARY

The sediments of the Tertiary are typically arranged in cyclical patterns. Each cycle begins with a minor transgression, as in the *Nonionella cockfieldensis* zone of the Jackson (U. Eocene) or the *Marginulina* zone of the Anahuac (Oligocene or Miocene).

This is followed by the main transgression, accompanied by relatively clear water deposits as in the Moody branch and *Heterostegina* zone.

Then follows the progressively regressive turbid-water deposits as in the *Discorbis* zone and the Catahoula (U. Oligocene or Miocene)

There is a strong suggestion in the clear-water, transgressive phase, that the transgression is due to decrease in rate at which sediments are brought into the area of deposition—rather than increase in rate of subsidence. In either case, the main pulse of the transgression need not have reached different parts of the regions at the same time.

The regional configuration of the modern Shelf supports this conclusion. Areas of major sedimentation like the Mississippi River Delta are regressive. The Mississippi River has built its delta seaward out to the edge of the Shelf. On the other hand, the Shelf off western Louisiana, where there are no large rivers, is 150 miles wide. Here there are limestone banks and other earmarks of transgressive deposition. Sediments deposited in these two areas might be interpreted, when deeply buried as occupying different positions in the sedimentary cycle, yet they are contemporaneous.

NERITIC FACIES IN THE RECENT

Another feature of the cycles in the Gulf region is that their area of typical occurrence is quite restricted—landward they grade into continental shales and sands, seaward they grade into solid shale sections. Eastward they grade into solid limestone of the Florida section and southward they grade into more sandy beds of the Rio Grande embayments. Incidentally, the major oil trends occur in the areas of well-developed cyclical patterns.

The sediments of the Continental Shelf west of the Mississippi, and east as far as Mobile, are predominately dirty sand and mud with very abundant small foraminifera. The beaches are dirty, fine grained sand.

At Pensacola on the east the beaches are sparkling white, medium grained sand. This condition extends outward across the continental shelf to about the twenty fathom line, some forty miles offshore. The sand is richly fossiliferous, but all samples from the sandy area of the Shelf are devoid of mud. Molluscs are common and foraminifera are very abundant. Many of the species occur at about the same depth that they occupy in the turbid western gulf region. But there are also conspicuous additions such as *Gypsina*, *Asterigerina*, *Amphistegina*, and several others which are abundant in the clean bottom-waters of the eastern area. These genera are totally lacking in the turbid waters to the west where *Pulvinulinella*, *Nonion*, *Nonionella*, *Rotalia* and *Elphidium* are the most abundant genera above the twenty fathom line. Exceptions occur in the western Gulf region on high banks where the faunal facies of the eastern Gulf region finds refuge in clear water.

The sediments of the middle Shelf also are very different in the eastern and western Gulf. To the east they are made up of shell material that covers an area

between the twenty and forty fathom lines. Rod-like algae and foraminifers predominate, but pelecypods, brachiopods, bryozoans and cup corals are also very abundant. Many of the mollusc fragments, as well as the algae and foraminifers, have a worn look as though rolled about by wave action. The foraminifer *Amphistegina* is a large form which has a worn rolled look. It forms about one-third of the foraminiferal population by number but possibly two-thirds or more by weight. *Asterigerina* and *Gypsina* are also abundant as are *Cibicides* and *Discorbis*.

In the western Gulf the sediments of the middle Shelf are silt and clay with minor amounts of fine sand.

The limits of the mid-Shelf sediments in the western Gulf are indefinite, and the unit is identifiable principally because it contains element of both inner and outer shelf facies.

The outer Shelf in the western Gulf region extends outward to about forty-five or fifty fathoms depth. The fauna of foraminifers is more rich and varied than in any other depth zone. It is distinguished by a great abundance of *Cibicides* and *Anomaline*, and by numerous abundant genera of *Lagenidae*. The seaward edge is in sharp contrast with the *Buliminidae* assemblage of the upper Slope.

BATHYAL FACIES IN THE RECENT

The break in slope between Shelf and Slope occurs at about 270 to 300 feet in the western Gulf region and there is a notable decrease in grain size of the silt and clay at about this depth.

The faunal line of demarcation is by far the most prominent feature of the change that occurs between Shelf and Slope sediments. It is most prominent and most sharp in the neighborhood of the bird-foot Delta of the Mississippi River. In that area the fauna changes in the distance of less than a mile from a dominant *Lagenidae* assemblage to one composed of 80 per cent or more *Uvigerina*. The *Uvigerina*-dominant area occupies a narrow band two or three miles wide. Seaward from that band the fauna is composed of the widely distributed upper slope assemblage of *Bulimina*, *Bolivina*, *Uvigerina* and *Cassidulina*.

The fact that these faunal differentiations are so sharp in the vicinity of the Delta suggests that the change is related to turbidity, and possibly to the depth to which light penetrates the water.

This suggestion finds support in the relationships in the eastern Gulf. In that clear-water area the contact of the outer neritic and inner bathyal faunal associations is less sharp, but it is clearly expressed nonetheless. It occurs at about the 75 fathom line as opposed to the 50 fathom line in the turbid western Gulf.

It is known that *Cibicides*, and many other genera, live attached to plants. Fifty to 75 fathoms is about the lower limit of light penetration and hence of plants. The faunal change that occurs between the bathyal and neritic zones could be due to the lower limit of plant growth.

SIGSBEE DEEP

The central basin of the Gulf, the so-called Sigsbee Deep, has an amazingly flat floor, especially when contrasted with the hummocky, basin pock-marked Continental Slope. The Woods Hole Expedition found well-bedded sand with some Continental-shelf foraminifers in the Sigsbee Deep. This suggests that turbidity currents have been active, and that they may account for the flat floor of the Sigsbee Deep. If we project the Continental Slope to the center of the Gulf, it appears possible that there may be several thousand feet of Recent and Pleistocene sands brought by density currents to the Sigsbee Deep.

CONTINENTAL FACIES IN THE RECENT

At the other end of the depth scale are the continental deposits adjacent to the northwestern Gulf. These include freshwater lake and cypress swamp, weakly brackish lake, strongly brackish lake and bay, and brackish marsh de-

posits. Each of these is characterized by a particular bio- and litho-facies.

The sediments of the fresh-water bog-lakes and swamps are high in plant remains and they contain abundant *Centropyxis* and *Difflugia*.

The weakly brackish lakes, with water from 100 to 1000 parts per million chloride content are floored with blue mud, banks of clam shells and some sand. Ninety per cent or more of the foraminifers are *Ammobaculites*.

In the open, current-swept portions of brackish bays, the fauna varies with the salinity, and the bottom sediments are blue mud, sandy mud and sand with numerous oyster banks. The foraminifers are *Ammobaculites* spp. *Rotalia beccarii* var. *tepida* and *Elphidium gunteri* var. *galvestonensis*. All three species have a very wide range of variation, which corresponds to the wide range of environmental conditions in these bays which are swept by daily tides, by occasional fresh water floods and by hurricanes. Maybe the bugs have to vary in order to meet the varying conditions—not individually, but specifically. When particularly adverse conditions kill off all but one variant, that variant contains the potentiality of producing all the others when environmental pressures are removed.

The current-swept portions of the marsh have bio- and litho-facies like those of the bays: blue mud with *Ammobaculites*, *Rotalia* and *Elphidium;* but the stagnant pools are characterized by black plant muck, and a fauna of foraminifers that is 100 per cent different from that found in open marsh water. Dominant genera are chitino-arenaceous representatives of *Haplophragmoides*, *Trochammina* and *Ammoastuta*. A few inches below the surface the black muck apparently alters to a dirty blue-gray mud.

SUMMARY OF BIOFACIES

The greatest difference between the bio- and litho-facies in the eastern and western Gulf appears to be due to differences in turbidity.

The greatest difference between shallow and deeper marine faunas (out to and including the upper part of the Continental Slope) may be due to light penetration, hence plant growth, hence food.

The pronounced difference between continental assemblages such as formed in fresh water, brackish water bays and brackish water marsh, appears to be due to water chemistry, particularly chlorinity and oxygen content.

SEDIMENTARY TECTONICS

There appears to have been rapid subsidence in the northwestern Gulf during most of the Tertiary—the rate of subsidence having been progressively greater from the marsh area out to the Continental Slope. An excess of clastic sediment kept pace with this subsidence during most of the Tertiary. There were short periods when decreased rate of sedimentation apparently resulted in temporary victory for subsidence with resulting deposition of clear water sediments in transgressing seas.

Variations in the degree of turbidity in the modern Gulf show that such changes in rate of sedimentation can be geographic as well as cyclical.

Typical cyclical patterns appear to have been favorable to oil accumulation in Gulf Coast Tertiary.

Other apparently valid generalizations are:

(1) Fine grained sediments can be deposited at or above wave base.

(2) The Continental Shelf is a platform which is built up by sedimentation—not a wave-cut bench.

(3) Sediments deposited in swamps or marsh may have tree roots and stumps in place, they may have channels scoured out, then filled with sand. They may have other generally accepted evidences of unconformity and still be part of a thicker, more rapidly deposited unit than the succeeding transgressive marine series—which

transgresses only because of temporary or local decrease in the rate at which sediments are brought into the area.

(4) Local temperature variations apparently have little or no effect on the continental facies. Temperature may play a subordinate part in effecting the differentiation of neritic and bathyal faunas.

APPLICATIONS

The most immediate geological application of these facies data, of course, is in the field of environmental interpretation.

The many ways in which facies interpretation is applied to exploration for oil are well known. The subject is much too extensive for more than mention in this paper. A few of the more common fields of application are:

(1) Stratigraphic correlation.
(2) Distribution of cyclical units up and down the dip and along the strike.
(3) Sedimentary tectonics, both regional and local.
(4) Sedimentary record of regional and local structural history.
(5) Distribution of oil sands in relation to depositional slope of a producing formation.
(6) Distribution of producing sands in relation to possible source beds.
(7) Distribution of source beds.

One aspect of stratigraphic correlation may be cited as an example. Some individual strata, rich in fossils, can be used locally as key beds, irrespective of the presence or absence of guide species. But the faunal aspect of such strata changes laterally along with other changes of facies, and this reduces their value as key beds. If the local faunules of such a stratum are plotted in terms of percentage abundance of the constituent genera, it will be found that the lateral changes in fauna can be interpreted in terms of gradual change of depositional environment. In this way the faunal changes can be used to strengthen, instead of weaken, the total stratigraphic analysis, and specifically the stratigraphic correlation.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, P. 238
DECEMBER, 1951

REVIEWS

An Introduction to the Study of Organic Limestones by J. Harlan Johnson. Colorado School of Mines Quarterly, vol. 46, no. 2, 185 pp., April 1951.

This publication is a revision of an earlier one bearing the same title and by the same author. (Colorado School of Mines Quarterly, vol. 44, no. 4, Oct. 1949.) The report necessarily involves considerable zoology and paleontology but this is balanced against such discussions of particular value to the sedimentary petrologist as structure, mineral composition and chemical composition of invertebrate hard parts and their contribution to the formation of limestones. Similar data are included on calcareous algae. A wealth of illustrations is provided showing structural details of individual forms and of limestones containing them. The report is one which the sedimentary petrologist dealing with calcareous rocks will find of much interest.

The number of pages in the new edition has been enlarged from 139 to 185, largely as a result of the increase in the number of illustrations from 61 to 104. Sections on "Worms and worm limestones" and "Arthropoda" have been added to the earlier sections on "Foraminifera," "Porifera," "Coelenterata," "Echinoderma," "Bryozoa," "Brachiopoda," "Mollusca" and "Calcareous Algae." Treatment of text material is generally similar to that in the earlier edition.

J. E. LAMAR
Illinois State Geological Survey
Urbana, Illinois

Chart Correlating Various Grain-Size Definitions of Sedimentary Materials compiled by Page E. Truesdell and David J. Varnes. United States Department of the Interior, Geological Survey, 1 p. 18×24 inches, 1950.

The chart does not indicate preference of the Geological Survey for any one size classification over another, nor is it intended to perpetuate the use of classifications based entirely on grain size if more useful classifications based on other factors can be developed. It does call attention, however, to the various classifications that are in use, and furnish an easy means of correlation for engineers, geologists and soil scientists who work with more than one classification.

When the chart was first published (in February, 1951) it was announced only in the Geological Survey's monthly list of publications, which goes to a comparatively small mailing list. Since we feel that wider circulation should be of interest and value to the public, we have sent copies to a number of organizations. Copies can be obtained, at 10 cents each, or 8 cents each in lots of 100 or more, from the Chief of Map Distribution, Geological Survey, Washington 25, D. C., or from the Distribution Section, Geological Survey, Denver Federal Center, Denver, Colorado.

(The statement presented above as a review, was taken from a letter to the Society by Mr. Eckel.—J. L. H.)

EDWIN B. ECKEL, Chief
Engineering Geology Branch
U. S. Geological Survey
Denver, Colorado

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 21, NO. 4, PP. 239–241
DECEMBER, 1951

ANNOUNCEMENTS

ANNUAL MEETING, SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

Biltmore Hotel, Los Angeles

March 24–27, 1952

The annual meeting of the S.E.P.M. will be held at the Biltmore Hotel, Los Angeles, California, on March 24, 25, 26, and 27, 1952. As in previous years the meeting will be held jointly with the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

In addition to presidential addresses and joint sessions with the other two societies, there will be separate technical sessions, symposia, and a field trip. The annual S.E.P.M. symposium will be on "Objectives in Modern Sedimentology and Paleontology." There will probably be another one on "Recent Marine Sedimentation." The field trip will be to type localities of several well-known formations which have excellent microfaunas.

President Tom Philpott has appointed K. O. Emery, Geology Department, University of Southern California, Los Angeles 7, California, to be program chairman for the S.E.P.M. Members planning to submit papers should notify the program chairman by Dec. 15 of the title and length of their papers. Abstracts, typewritten, double-spaced, and in duplicate, are due on or before Jan. 1.

REPORT ON THE ESTABLISHMENT OF AN INTERNATIONAL SEDIMENTOLOGICAL UNION

As reported in the *Journal* (December 1948 and April 1949) by Dr. Dana Russell, a proposal for the creation of an International group of sedimentologists was put forward at an informal meeting of sedimentary petrologists in London on September 1, 1948. This proposal was discussed and finally adopted during the Third International Congress in Sedimentology held in Holland from July 5th to 12th, 1951. The following notes of the meeting were made by the Congress secretary, Dr. Tj. H. van Andel:

A preliminary meeting of delegates[1] of all countries present at the Congress submitted a proposal concerning the establishment of a union to be entitled the International Union of Sedimentologists.

The following points were discussed:

1. Should the Union be a combined group of both sedimentologists and Quaternary geologists or an independent union of sedimentologists? The meeting decided in favor of an independent Union that will keep in close touch with Quaternary geology.
2. It was proposed to use the term Association in place of Union as the latter term would imply that the organization would be sponsored by Unesco. The meeting decided in favor of the term Union.
3. It was decided that a preliminary committee would be appointed and that this preliminary committee would prepare a constitution and laws for proposal at a meeting to be held at the Geological Congress in Algiers in 1952. It was further proposed and accepted that the preliminary committee also consider the question of federalized or centralized organization.
4. It was proposed that a delegate be appointed from each country and the meeting decided that as Belgium had priority in the initial organization of a Congress, Professor Tavernier would join the temporary committee as representative of Belgium.
5. The Committee (listed below) as proposed to the meeting was elected after withdrawal of Mr. Shearman in favor of Dr. P. Allen as representative of the United Kingdom.

[1] Eighty-eight delegates were present representing ten countries.

The complete resolutions accepted run as follows:

a. An International Union of Sedimentologists has been established at this Congress.
b. A preliminary Committee has been elected in order to prepare for proposal a constitution and laws for this Union.
c. The Union will promote biannual Congresses.
d. In the first year a membership fee of one dollar will be asked from each member to cover this period.
e. Once each four years a series of reviews on the progress of sedimentology in different countries, including a list of references, will be published for the use of Members.
f. At the Geological Congress at Algiers a meeting of the members will adopt a constitution and elect a board.

The preliminary committee consists of:

President:	Mr. Doeglas	Netherlands
Secretary:	Mr. Vatan	France
	Mr. Allen	United Kingdom
	Mr. Correns	Germany
	Mr. Griffiths	United States of America
	Mr. Hansen	Denmark
	Mr. Tavernier	Belgium

It was informally suggested that the *Journal* would be the most practical medium for communications concerning the International Union of Sedimentologists.

This report would not be complete without reference to the International Congress of Sedimentologists. This series of meetings commenced in Belgium with "La Geologie des terrains Recents dans l'Ouest de l'Europe," Session Extraordinaire des Societes Belges de Geologie in September 1946; the second meeting took place in France, "Congres, Sedimentation et Geologie du Quaternaire," 1949 and the Third International Congress of Sedimentology was held in Holland in July 1951.

The Netherlands Congress comprised five days of field excursions covering areas from Groningen in the north to Dordrecht in the south with two days of papers and discussions at the Agricultural University of Wageningen. The proceedings were available in print before the meetings leading to many interesting discussions following presentation of the papers. The excursions dealt with Quaternary sedimentation in the Netherlands and the detailed mapping of thin zones was something of a revelation; perhaps the most interesting feature was the excursion to the "polders" where a shallow marine sedimentational environment has been drained and studied during reclamation of the land. It is rare indeed for a sedimentologist to have the opportunity of seeing an environment in operation and then to study the deposits actually formed in this environment. The Dutch sedimentologists have taken full advantage of this unique opportunity.

This eminently successful and interesting Congress closed with an invitation by Mr. K. Hansen, on behalf of Mr. N. Neilsen, for the Union to hold its Fourth Congress in Denmark in 1954 at the Shalling Laboratory at Esbjerg which the assembled members accepted with enthusiastic thanks to Denmark.

J. C. GRIFFITHS
Department of Earth Sciences
The Pennsylvania State College
State College, Pennsylvania

M. THEODORE KEARNEY FOUNDATION OF SOIL SCIENCE

The University of California announced on October 19, 1951, the establishment in the College of Agriculture of the M. Theodore Kearney Foundation of Soil Science. The new foundation will be endowed with the proceeds of the bequest of Mr. Kearney, prominent rancher in the Fresno area in the latter part of the last century, who died in 1906, leaving to the University his estate which included the famous Kearney Vineyard in Fresno County. The endowment now amounts to $2,268,000.

The foundation will be devoted to the advancement of knowledge of soil science including soil-water-plant relations,

through basic physical, chemical, biological, and hydrological research, with particular reference to arid and semi-arid farming regions. It will also be designed to strengthen the services of the University in the education and training of soil scientists and teachers of soil science and closely related subjects, to the end that the farmers of California may be better advised as to the growing of plants which will yield a fair return to producers and maximum satisfaction to consumers.

The current College of Agriculture soil program, which gradually will be strengthened and expanded by the foundation, includes research on the physical behavior of soils, their structural arrangement, the alteration they experience when worked, their infiltration by downward moving water and the laws governing such infiltration. The soil chemistry problems of alkali soils and their cropping methods are being studied both in the field and the laboratory, looking toward permanent reclamation and agricultural use for such soils. Other studies include the behavior of important chemical ions and their uptake by plants, seeking further information of problems connected with fertility; direct fertility studies in relation to soil types; the palatability and nutritive value to livestock of forage crops produced on soils of different fertility levels; the clay minerals of the soil and the part they play in soil chemistry and physics; and soil surveys and land classifications of the agricultural, grass, and forested areas of California.

The Kearney Foundation will be administered by a director within the present framework of the University of California College of Agriculture. Eventually additional outstanding scientists will be added to round out a well-balanced staff and program of soil investigations.

College of Agriculture
University of California

Journal
of
Sedimentary Petrology

VOLUME 21
MARCH, 1951-DECEMBER, 1951
NOS. 1-4

J. L. HOUGH, EDITOR

PUBLISHED BY THE
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
A DIVISION OF
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Box 979, Tulsa, Oklahoma

Journal of Sedimentary Petrology

INDEX TO VOLUME 21

Adams, G. I., cited....63, 80
Adams, J. E., cited....72, 76, 80
Ajibik quartzite (Huronian)....141
Albatross—Swedish deep sea expedition....82
Albrecht, W. H., cited....20
Aldrich, H. R., cited....105, 108
Allen, E. T., cited....35, 37, 46
Allen, P., cited....206, 212
Allen, T. V., cited....227, 232
Alling, H. L., cited....63, 80, 191, 194
Allison, L. E., cited....158, 161
Allison, V. C., cited....104
Amato, F. L., cited....224
Ammoastula....236
Ammobaculites....236
Amphistegina....234, 235
Anadarko Basin....79
Anahuac fm. (Olig.-Miocene)....234
Ancilla clay (Olig.-Miocene)....40
Andree, K., cited....30, 31
Andrews, D. A., cited....11
Anglesean clay (Oligocene)....44
Announcements....60, 239
Anomaline....235
Antelope Valley (California)....147
Apfel, E. T., cited....105, 108
Argillaceous sediments, color of....231
Arkin, H., cited....174, 177
Arrhenius, G., cited....84
Artemia gracilis....117
Asterigerina....234, 235
Attapulgite-Sepiolite....226–229
Augite-rich beach sand, Grenada, B. W. I....200
Australia—pisoliths, ooliths and calcareous growths in caves in....85

Bagnold, R. A., cited....164, 169, 172
Baker, A. A., cited....74, 80
Baker, C. L., cited....80
Baker, G., articles by....34, 85
Baker, G., cited....104
Ball, C., cited....227, 231
Ball, J., cited....109, 110, 117, 120
Bannahan, A., cited....224
Barnes, V. E., cited....28, 30, 31
Bastin, E. S., cited....37, 45, 46
Baudisch, O., cited....12, 20, 21
Bays, C. A., cited....65, 80
Beach sand, occurrence and derivation of at Grenada, B. W. I....200
Beach sands at Los Ojos de Agua de San Telmo, Michoacan, Mexico....195
Beach sands of the Mediterranean coast of Egypt....109
"Beach sands of the Mediterranean coast of Egypt," remarks on....185
Becker, G. F., cited....165, 172
Belteropore advancement....29
Beltian quartzite (Pre-Cambrian)....142
Bénard, J., cited....18, 20, 21
Bennett, H. S., article by....200
Bertram, G. C. L., cited....24, 25
Big Belt Mountains....142
Biotic and lithic facies, relationship of in Recent Gulf Coast sedimentation....233
Biscayne Bay, Florida, sieve analysis of sediments from....178
Black Hills....64, 70
Black, M., review of book revised by....59
Blanpied, B. W., cited....72, 77, 81
Bodman, G. B., cited....173, 177
Bolivina....235
Bradley, W. F., cited....11, 232
Bradley, W. H., cited....75, 80
Bramlette, M. M., cited....231
Branson, E. B., cited....77, 80
Brauch, W., cited....29, 31
Bray, R. H., cited....8, 11
Brewer, R., cited....205, 212
Briggs, L. J., cited....173, 177
Brotherhood, G. R., cited....182
Brotzen, F., cited....221, 224
Bulimina....235
Buliminidae....235
Bullard, F. M., article by....195
Burrows, fossil....141
Bush, J., article by....178

Calcareous growths in limestone caves in Australia....85
Calcite types in LeGrand limestone section, Iowa....192
California, lake sediments from....151
California, playa sediments from....147
Calkins, F. C., cited....141, 146
Camp, B. H., cited....182
Capitan Reef....72
Cardium edule....47
Carroll, Dorothy, article by....205
Carroll, Dorothy, cited....205, 212
Casagrande, A., cited....174, 177
Cassidulina....235
Catahoula fm. (U. Olig.-Miocene)....234
Caves in Miocene limestone in Australia....85
Central Basin Platform (Texas)....71, 72
Centropyxis....236
Chaplin oolite (Kinderhookian)....189
Chapman, C. A., book reviews by....58, 122
Chart correlating various grain-size definitions, review of....238
Chaudron, G., cited....18, 20, 21
Chayes, F., cited....172
Cheney, M. G., book review by....123
Chert in LeGrand limestone section, Iowa....192
Chironomidae....155
Chlorite....227–231
Chugwater fm. (Triassic)....72, 77, 78
Cibicides....235
Clarke, F. W., cited....76, 80
Clay minerals in sediments, general conclusions regarding occurrence....227
Clays, marine, with pyrite....40

Cloud, P. E., cited....28, 30, 31
Coal, brown, with marcasite.... 34
Coeur D'Alene Mountains.... 141
Colton, R. R., cited....174, 177
Comparison chart for visual percentage estimation, A.... 32
Continental Shelf of Gulf of Mexico.233–236
Correns, C. W., cited....228, 232
Cox, G. F., cited....142, 146
Crane, E. J., cited.... 108
Crenshaw, J. L., cited....35, 37, 46
Cretaceous evaporites in U. S.... 74
Crickmay, G. W., cited....219, 224
Cumulative curve, derivation of size frequency curve from.... 178
Cyclammina.... 44
Cyclical patterns of Tertiary sedimentation in the Gulf region.... 234
Cyclical sedimentation at LeGrand, Iowa.... 193

Dake, C. L., cited....142, 146
Dana, J. D., cited.... 31
Dane, C. H., cited....74, 80
Dapples, E. C., cited.... 172
Davidson, C. F., cited.... 185
Day, P. R., cited....174, 177
Deane, C., cited....92, 104
DeBoer, J. H., cited.... 21
Deep sea expedition—*Albatross*.... 82
DeFord, Ronald, K., cited....191, 192, 194
Delaware Basin (Texas)....71, 72
Denison, R., cited.... 108
Deposition of sand.... 164
Depositional environment of red and green shales, The.... 226
Depth of disturbance of sand on sea beaches by waves.... 131
Derivation of size frequency curve from the cumulative curve.... 178
Devonian evaporites in U. S.... 67
Diagenesis.... 5
Diagenetic changes in clay minerals.229, 231
Dietz, R. S., cited....228, 232
Difflugia.... 236
Discorbis zone....234, 235
Discussion....121, 183
Discussion, "What is sedimentology?". 121
Doeglas, D. J., cited....183, 184
Dolomite.... 82
Dolomite, formation of.... 28
Dolomite in limestone section at LeGrand, Iowa.... 191
Dryden, L., book review by.... 55
DuBois, E. P., cited....65, 80
Dunn, E. J., cited....211, 212

Eardley, A. J., cited....117, 120
Earlandia.... 9
Eckel, Edwin B., review by.... 238
Edwards, A. B., article by.... 34
Edwards, A. B., cited....34, 37, 46
Egypt, beach sands from Mediterranean coast of.... 107
Ellison, S. P., Jr., article by.... 214
Ellison, S. P., Jr., cited....224, 231
Elphidium.... 234
Elphidium gunteri var. *galvestonensis*... 236
Elsinore fault zone.... 151
Elsinore Mountains.... 151
Emery, A. H., cited.... 108
Emery, K. O., article by.... 105
Emery, K. O., cited....25, 150
Endell, J., cited....227, 232
Endell, K., cited....227, 232
Endothyranella.... 9
Engel, R., cited....151, 153, 161
English River fm.... 193
Epidote, remarks on.... 183
Erdmann, E., cited....40, 46
Eudyptes pachyrhynchus atratus.... 22
Evans, O. F., cited.... 54
Evaporite deposition, symposium.... 213
Evaporites, occurrence, and lithologic association in U. S.... 63
Evaporites, origin.... 75

Fabric of sediments.... 162
Facies, biotic and lithic, in Recent Gulf Coast sedimentation.... 233
Faul, H., cited....141, 144, 145, 146
Fenton, C. L., cited....141, 146
Fenton, M. A., cited....141, 146
Ferric oxide, gamma, in sediments.... 12
Fleming, C. A., article by.... 22
Fleming, R. H., cited....216, 225
Folk, R. L., articles by....32, 127
Foraminifera.... 112
Foraminifers....217, 219
Foreset beds, orientation of sand grains in.... 168
Frank-Kamenecky, V. A., cited....18, 20
Fraser, H. J., cited....165, 166, 172
Frebold, H., cited....48, 54
Frenzel, H. N., cited....72, 76, 77
Fricke, R., cited.... 20
Frostick, A. C., article by.... 85
Frostick, A. C., cited.... 102

Galliher, E. W., cited....45, 46, 230, 232
Gamma ferric oxide in sediments.... 12
Gastropoda....111, 112
Geology, annual output of articles on.. 106
Gilbert, G. K., cited....164, 172
Ginter, R. L., cited....37, 46
Glauconite....192, 230
Glauconite, residual in LeGrand limestone....192, 193
Glemser, O., cited....12, 21
Glen Ivy fault.... 151
Globigerian.... 219
Goldman, M. I., cited.... 121
Grabau, A. W., cited....76, 80, 81
Grain orientation in sands and sandstones.... 161
Grain-size definitions, chart correlating various, review of.... 238
Graton, L. E., cited....165, 166, 172
Great Salt Lake.... 117
Green River fm. (Eocene).... 75
Griffiths, J. C., cited.... 182
Grim, R. E., article by.... 226
Grim, R. E., book review by.... 122
Grim, R. E., cited....8, 11, 232
Grubenmann, U., cited.... 122
Gulf Coast region.... 64

Gulf Coast sedimentation (Recent).... 233
Gypsina.....234, 235
Gypsum Basin (Colorado).....70, 71, 77, 78
Gypsum Spring fm. (Triassic)..... 73
Gyraulus vermicularis (Gould)..... 155

Haayman, P. W., cited..... 21
Hadding, A., cited.....230, 232
Hägg, G., cited.....13, 16, 18, 21
Hahn, F. L., cited..... 12, 21
Hall, T. S., cited.....44, 46
Hamilton, J. E., cited.....24, 25
Hamilton, W. A., cited.....219, 221, 224
Hamilton, W. B., article by..... 147
Hampton fm. (Kinderhookian)..... 189
Hanna, M. A., cited..... 31
Haplophragmoides..... 236
Hares, C. J., cited.....40, 46
Harley, J. E., cited.....205, 212
Hatch, F. H., review of book by.....58, 59
Haul, P., cited.....18, 21
Hawkesbury sandstone (Triassic)..... 205
Haynesville fm. (Triassic)..... 74
Hazzard, R. T., cited.....63, 67
Heald, K. O., cited..... 108
Heilmann, E. L., cited..... 21
Helisoma tenue californiense Baker..... 155
Hendricks, S. B., cited.....230, 231, 232
Hendrickson, A. H., cited.....173, 177
Heroy, W. B., cited.....105, 108
Hershey, H. G., cited.....63, 67
Hertrich, M., cited..... 21
Heterostegina zone..... 234
Hicks, D., cited.....227, 232
Hills, J. M., cited.....72, 76, 81
Hilmy, M. E., article by..... 109
Hilmy, M. E., cited..... 185
Hoffmeister, J. E., cited.....219, 224
Hogland, H., cited.....221, 224
Holmes, C. D., cited.....168, 172
"Hornsteinbreccia"..... 30
Hough, J. L., book review by..... 59
Hunt, H. A., cited.....97, 104
Hyalocylix (?) annulata..... 44
Hydrobiotite..... 227

Idaho, Pre-Cambrian mud cracks from. 141
Illinois Basin.....64, 65, 69
Illite.....226–231
Imlay, R. W., cited.....72, 74, 81
Ingerson, E., cited.....162, 172
Introduction to the study of organic limestones, book review..... 238
Introduction to theoretical igneous petrology, book review..... 122
Iowa Basin.....64, 79
Ireland, H. A., cited.....191, 194
Iron sulphides, supergene, some occurrences in relation to their environments of deposition..... 34
Isrealsky, M. C., cited.....221, 224

Jackson fm. (U. Eocene)..... 234
Joachim dolomite (Devonian)..... 65
Johnson, D. W., cited.....138, 140
Johnson, Harlan J., book review by..... 238
Johnson, H. R., cited.....147, 150
Johnson, J., cited.....46, 104
Johnson, M. W., cited.....216, 225
Journal of Paleontology, discussion of articles in, from 1940–1950..... 219
Jurassic evaporites in U. S..... 72

Kaolinite.....226–228, 231
Kaufmann, A., cited..... 12, 21
Khalil, A. M. Y., cited.....112, 120
Kindle, E. M., cited.....141, 146
King, C. A. M., article by..... 131
King, P. B., cited.....72, 76, 81
King, R. H., cited..... 81
Koessenerstrata (U. Triassic)..... 28
Kordes, E., cited..... 13, 21
Krause, A., cited..... 20, 21
Kroenlein, G. A., article by..... 63
Krumbein, W. C., article by..... 63
Krumbein, W. C., cited.....120, 130, 172, 206, 207, 210–212
Krumbein, W. C., book review by..... 123
Krynine, P. D., cited.....81, 130
Kuenen, Ph. H., cited.....150, 215, 224

Ladd, H. S., cited.....219, 224
Lagena..... 9
Lagenidae..... 235
Lake Elsinore, California, sediments of. 151
Lake Mead..... 175
Lamar, J. E., cited.....227, 232
Lamar, J. E., book review by..... 238
Lamellibranchia.....111, 112
Lang, W. B., cited.....76, 78, 79, 81
Larsen, E. S., cited.....153, 161
Laudon, L. R., cited.....181, 191, 194
Lawson, Ralph W., article..... 189
Lawson, Ralph W., cited.....191, 194
LeDuc reefs..... 67
Lefort, J., cited.....12, 16, 18, 20, 21
"LeGrand beds" (Mississippian), LeGrand, Iowa..... 189
Leinz, Shepard W., article by..... 233
Lemberg stain for dolomite..... 29
Levorsen, A. I., cited..... 108
Limestone caves..... 85
Limestones, lithology of, at LeGrand, Iowa..... 189
Limnology, Lake Elsinore, California... 153
Lindgren, W., cited.....7, 11
Link, T. A., cited..... 81
Lithic facies, relation to biotic facies in Recent Gulf Coast sedimentation. 233
Lithologic association of evaporites in the U. S..... 63
Lithology of limestones at LeGrand, Iowa..... 189
Lloyd, E. R., cited..... 81
Loess, connection of epidote with..... 183
Lohse, E. A., discussion by..... 121
Longitudinal ripple marks in mud and sand..... 47
Louann salt.....74, 77, 78
Lowman, Shepard W., article by..... 233
Lowman, Shepard W., cited....219, 221, 224

MacAlpine, A. J., cited.....3, 11
Madera formation..... 3
Maegdefrau, K., cited.....29, 31
Mahmud, A. J., cited.....173, 177

Mancos fm. (Cretaceous) ... 176
Mann, J. F., Jr., article by ... 151
Mann, J. F., Jr., cited ... 158, 161
Mansfield, G. R., cited ... 74, 81
Marcasite ... 34
Marginulina zone ... 234
Marine shales ... 214
Maroon fm. (Penn.-Perm.) ... 70
Martin-Kaye, P., article by ... 200
Marquez shale (Eocene) ... 219
McEwen, G. F., cited ... 155, 161
McKee, E. D., cited ... 81
McKinstry, H. E., cited ... 108
McLane, J. W., cited ... 173, 177
Mediterranean coast of Egypt, beach sands of ... 109
Melhuish, C. A., cited ... 92, 104
Mesa Verde fm. (Cretaceous) ... 176
Mexico, beach sands at Los Ojos de Agua de San Telmo ... 195
Michel, A., cited ... 18, 20, 21
Michigan Basin ... 64, 65, 68, 69, 70, 79
Microfossils as environmental indicators in marine shales ... 214
Microfossils, kinds ... 217
Midland Basin (Texas) ... 72
Miller, R. R., cited ... 148, 150
Millot, George, cited ... 227, 232
Millot, George, review of book by ... 122
Mills, F. C., cited ... 182
Mills, Richard A., article by ... 195
Milner, H. B., cited ... 102
Mineralogy of Mediterranean beach sands ... 117
Minnelusa fm. (Penn.) ... 70
Mississippi River Delta ... 234, 235
Mississippian evaporites in U. S. ... 68
Moerman, J. D., cited ... 3, 11
Mohr, C. L., cited ... 81
Mojave Desert ... 147
Montana, Pre-Cambrian mud cracks from ... 141
Montmorillonite ... 226–231
Morischima, M., cited ... 221, 224
Mud cracks from Idaho and Montana ... 141
Muller, J. E., cited ... 184
Murrieta Graben ... 151
Mytilus edulis ... 47

Nagelschmidt, G., cited ... 227, 232
Natland, M. L., cited ... 219, 221, 224
Newhouse, W. H., cited ... 34, 46
New Mexico, Pennsylvanian sedimentation in northeastern Socorro County ... 3
New Red Sandstone (Scotland) ... 169
Noll, W., cited ... 228, 232
Nonion ... 234
Nonionella ... 234
Nonionella cockfieldensis zone ... 234
Norton, G. H., cited ... 81
Norton, R. D., cited ... 219, 221, 224

"Oberjura-Vorfeld breccia" ... 30
Occurrence and lithologic associations of evaporites in the U. S. ... 63
Odontaspis ... 44
Oinomikado, T., cited ... 221, 224
Olearia lyalii ... 22
Ooliths in limestone caves in Australia ... 85
Oolitic beach sand, Egypt ... 109
Oolitic beds in limestone at LeGrand, Iowa ... 193
Ordovician evaporites in U. S. ... 65
Organic limestones, an introduction to the study of, book review ... 238
Orientation, grain, in sands and sandstones ... 162
Otto, G. H., cited ... 182

Paleoecology of shale and evaporite deposition, symposium on ... 213
Palmer, Robert, cited ... 197, 199
Paradox Basin ... 64, 70, 79
Parker, F. L., cited ... 216, 219, 221, 224
Parr, W. J., cited ... 36, 46
Pebbles from a pothole: a study in shape and roundness ... 205
Pecora, W. T., cited ... 108
Pennsylvanian evaporites in U. S. ... 69
Pennsylvanian sedimentation in northeastern Socorro County, New Mexico ... 3
Percentage estimation, chart for ... 32
Permian Basin ... 76
Permian evaporites in U. S. ... 70
Petrology of the Igneous Rocks, The (Textbook of Petrology, vol. 1), review of book ... 58
Petrology of the Sedimentary Rocks, The (Textbook of Petrology, vol. 2), review of book ... 59
Pettersson, H., cited ... 82, 84
Pettijohn, F. J., cited ... 120, 127, 130, 182
Phalen, W. C., cited ... 63, 75, 81
Phleger, F. B., cited ... 219, 221, 224, 225
Phosphoria (Embar) (Permian) sediments ... 71
Physella osculans (Haldeman) ... 155
Pierre shale (U. Cretaceous) ... 228
Pisoliths in limestone caves in Australia ... 85
Playa sediments of Rosamond Dry Lake, California ... 147
Plumley, W. J., cited ... 127, 130, 206, 211, 212
Port Campbell, Victoria, limestone cave deposits ... 85
Porters Creek shale (Eocene) ... 228
Pothole, pebbles from ... 205
Pouillard, E., cited ... 20, 21
Pre-Cambrian mud cracks from Idaho and Montana ... 141
Preuss sandstone (Triassic) ... 73
Pritchard, G. B., cited ... 44, 46
Problem of dolomite formation considered in the light of research on dolomites in the Sonnwendmountains, (Tirol), The ... 28
Provenance, transport, and deposition of Rhine sediments, review of book ... 55
Pulvinulinella ... 234
Pyrite ... 34
Pyrite, residual in LeGrand limestones ... 192

Quartz in shales ... 226
Quinlan, J. J., article by ... 141

Ransome, F. L., cited ... 141, 146

Rapid substitute for textural analysis. 173
Rastall, R. H., review of book by..... 59
Rayleigh, Lord, cited..205, 207, 208, 211, 212
Read, C. B., cited.....10, 11
Recent sediments, clay mineral composition of..... 228
Red beds..... 63
Reed, R. D., cited.....151, 161
Reeside, J. B., cited.....74, 80
Reiche, P., cited.....10, 11
Relations entre la constitution et la genese des roches sedimentaires argileuses, book review..... 122
Renz, H. H., cited.....221, 225
Results of *Albatross* deep sea expedition. 82
Revelle, Roger, cited.....228, 230, 232
Reviews.....55, 122, 238
Richter, R., cited.....47, 54
Ripple marks..... 141
Ripple marks, longitudinal, in mud and sand..... 47
Robinson, W. O., cited.....173, 177
Rodgers, J., cited.....30, 31
"Rodoorn" soil..... 12
Rominger, J. G., cited..... 172
Rosamond Dry Lake, California, playa sediments of..... 147
Ross, C. S., cited.....230–232
Rotalia..... 234
Rotalia beccarii var. *tepida*..... 236
Roth, R., cited.....76, 81
Roundness of pothole pebbles..... 205
Roundness, in textural maturity..... 127
Rowland, R. A., cited.....162, 172
Royer, L., cited.....100, 104
Rummelen, van, F. F. F. E., discussion by..... 183

Said, R., cited.....219, 221, 224, 225
Sand, depth of disturbance on sea beaches by waves..... 131
Sander, B., cited.....31, 84, 172
Sandia fm..... 3
Sands, grain orientation in..... 161
Sandstones, grain orientation in..... 161
Schoon, T., cited..... 21
Schott, W., cited.....221, 225
Schwarzacher, W., article by..... 161
Schwarzacher, W., cited.....31, 84
Sea lions as geological agents..... 22
Sedimentary rocks, stages of textural maturity in..... 127
Sedimentation, Pennsylvanian, in northeastern Socorro County, New Mexico..... 3
Sedimentology..... 121
Sedimentology, trends in literature in.. 105
Sediments of Lake Elsinore, California. 147
Sediments, playa, from California..... 147
Shales, marine..... 214
Shales, Paleozoic of Illinois..... 226
Shales, red and green..... 226
Shape of pothole pebbles:..... 205
Sherman, I., article by..... 173
Shrock, R. R., cited...141, 142, 146, 168, 172
Shukri, N. M., cited.....118, 120, 185
Shukri, N. M., discussion by..... 183
Sidwell, R., article by..... 3
Siegrist, M., cited..... 105
Sigsbee Deep..... 235
Silurian evaporites in U. S..... 65
Simpson, E. D., cited.....147, 150
Size-frequency curve, derivation of, from cumulative curve..... 178
Sloss, L. L., cited.....64, 77, 81
Sloss, L. L., review of book by..... 123
Slossen, J. E., cited.....175, 176, 177
Smackover limestone (Triassic)..... 74
Smith, F. G., cited.....35, 42, 46
Snyder, F. G., article by..... 26
Söderholm, G., cited..... 21
Some occurrences of supergene iron sulphides in relation to their environments of deposition..... 34
Sonnwendmountains (Tirol)..... 28
Sorting, in textural maturity..... 127
Spartina..... 53
Spooner, W. C., cited.....72, 77, 81
Stach, L. W., cited.....211, 224
Stages of textural maturity in sedimentary rocks..... 127
Stalactite, from Saltville, Va..... 26
Starke, K., cited.....13, 20, 21
Stocks, H. B., cited.....38, 46
Stone, R. W., cited.....63, 75, 81
Stratigraphy and sedimentation, review of book..... 123
Striped Peak fm. (Pre-Cambrian)..... 141
Substitution for textural analysis..... 173
Sverdrup, H. U., cited.....216, 225
Symposium on paleoecology of shale and evaporite deposition..... 213

Tarr, W. A., cited.....35, 46
Tasman, Mehilika, cited.....221, 224
Taylor, G. G., cited..... 108
Tertiary evaporites in U. S..... 75
Textbook of Petrology (vol. 1, The Petrology of Igneous Rocks), review of book..... 58
Textbook of Petrology (vol. 2, The Petrology of Sedimentary Rocks), review of book..... 59
Textural analysis, a rapid substitution for..... 173
Textural maturity, in sedimentary rock. 127
Thiessen, R., cited.....36, 37, 38, 46
Thompson, P. G., cited.....147, 148, 150
Three Forks fm. (Devonian)..... 67
Tidal flats of the Waddensea..... 47
Tilley, C. E., cited..... 108
Topset beds, grain orientation of in dunes..... 169
Trails, fossil..... 141
Transportation of sand..... 164
Trask, P. D., cited.....112, 120, 129
Trends in literature on sedimentology.. 105
Triassic evaporites in U. S..... 72
Trochammina..... 326
Tromp, S. W., cited.....221, 225
Truesdell, Page E., review of chart by. 238
Trusheim, F., cited.....47, 54
Tulecki, J., cited..... 21
Turner, W., cited.....24, 25
Twenhofel, W. H., cited.....46, 104, 161

Underclays, Pennsylvanian of Illinois.. 227
Unusual stalactite from Saltville, Va., An.... 26
Uvigerina.... 235

Van Andel, T. H., review of book by.. 55
Van der Marel, H. W., article by..... 12
Van Rummelen, F. F. F. E., cited..... 184
Van Rummelen, F. H., cited.....183, 184
Van Straaten, L. M. J. U., article by... 47
Variscite (?), residual in LeGrand limestones.... 192
Varnes, David J., review of chart by... 238
Verdoorn, F., cited.....105, 108
Verwey, E. J. W., cited.....13, 18, 21
Viehmeyer, F. J., cited.....173, 177
Virginia, stalactite from..... 26

Waddensea, tidal flats of..... 47
Wadell, H., cited.....162, 172
Wagner, W. R., cited.....141, 146
Walhstrom, E. E., review of book by.. 122
Walton, W. R., cited.....219, 221, 225
Warn, G. F., article by..... 3
Waves, depth of disturbance of beach sands by.... 131
Welch, P. S., cited..... 161
Wells, A. K., review of book by..... 58
Wells, M. K., review of book by..... 58
Welo, L. A., cited.....12, 20, 21
Wengerd, S. A., cited.....191, 194
Wentworth, C. K., cited.....108, 182, 212
Werner anhydrite.....74, 78
Weynschenk, R., articles by.....28, 82
Weynschenk, R., cited.....31, 84
"What is 'sedimentology'?", a discussion.... 121
Wheeler, H. E., article by..... 141
Whitewood-Bighorn dolomite (Ordovician).... 65
Wilder, F. A., cited..... 81
Wildomar fault..... 151
Willard fault..... 151
Williams, W. W., cited..... 136
Williamson, E. D., cited..... 104
Willis, B., cited.....151, 161
Williston Basin.....64–66, 68, 79
Wilpolt, R. H., cited.....3, 11
Wilson, E. A., cited.....24, 25
Wood, G. H., cited.....10, 11
Wood, H. O., cited.....151, 161
Woodford black shale (Devonian)..... 219
Woolnough, W. G., cited..... 81

Young, A. A., cited..... 151

Zalophus byronia..... 25
Zalophus hookeri..... 24
Zerrweck, W., cited..... 20
Zingg, Th., cited.....206, 212
Zostera..... 53

Diatoms of Historic Importance

One of the world's outstanding private collections of diatoms, formerly the property of J. R. Bartholomew, Research Associate of the Farlow Herbarium, Harvard University, is now available through Ward's to the world of science at large. Consisting of material taken from more than a thousand different collections and cleanings, made during a period of over one hundred years, the collection embraces numerous localities represented in Tempere and Paragallo "Diatomées du Monde Entier." Many of the specimens came from the original collections of such prominent workers as W. A. Terry, James Smith, R. D. Nevius, H. H. Gran, and V. L. Eardley-Wilmot, among others. Specimens which are of historic interest are being provided on microscope slides, while the remainder are available in bulk form. *A list of individual offerings is available on request.*

WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.

3000 RIDGE ROAD EAST · ROCHESTER 9, N.Y.

Oceanographic Instruments

***SONIC SEDIMENTATION SAMPLERS, as designed by LaFond, Dietz, and Knaus.
***MECHANICAL SEDIMENTATION SAMPLERS, all patterns, "Scoop-fish" or Underway Sampler, cup type; Deep Sea Grab Sampler, Snapper type; Standard Snapper Samplers; Sediment Coring Devices, for cores 6" to 12';
***DREDGES, hand and power types, with removable sieves
***DEEP SEA REVERSING THERMOMETERS, all models
***REVERSING WATER BOTTLES
***CURRENT METERS, Mechanical and Electronic types
***WINCHES, Oceanographic, Hand and Power types
***UNDERWATER CAMERAS, for Lakes and Oceans
***PORTABLE TEMPERATURE RECORDERS, self contained
***ELECTRONIC TEMPERATURE, CONDUCTIVITY, and DEPTH RECORDER
***MULTI CHANNEL TEMPERATURE RECORDING SYSTEMS (from 1 to 16 Stations)
***FLOW METERS FOR LARGE PLANKTON NETS
***METER WHEELS, all types, in Meters, Feet and Fathoms
***PLANKTON NETS, all sizes
***PLANKTON SAMPLERS
***OCEANOGRAPHIC WIRE, Galvanized, Stainless Steel & Nylon coated

We have established an international reputation as developers and fabricators of quality instruments for oceanographic research. Our glassblowing and electronic laboratories are staffed by a well qualified scientific and technical staff.

KAHL SCIENTIFIC INSTRUMENT CORP.
P.O. BOX 1166 EL CAJON (SAN DIEGO) CALIF.
Eastern Office: 50 West 3 St., New York 12, N.Y.

WILEY

Coming in January—

The only book to give the petrological and theoretical background for the study of *all* kinds of rocks—igneous, sedimentary, and metamorphic . . .

THEORETICAL PETROLOGY

By Tom. F. W. Barth

Formerly Professor of Geochemistry at the University of Chicago; now Director of the Geological Museum at the University of Oslo.

This book is an exact and comprehensive scientific study of the rock-making processes and an interpretation and synthesis of the existing quantitative data. This includes:

- field data from all over the world
- experimental data from geophysical and geochemical laboratories
- theoretical data of the research workers in geology, chemistry, and physics.

From these data—collected, organized, and interpreted—Dr. Barth sketches the cyclic history of the rock masses of the earth's crust: their origin, evolution, transfiguration, destruction, and redevelopment.

Outline of the Book

Part I. Physics and Chemistry of the Earth
Part II. Formation of Sedimentary Rocks
Part III. Igneous Rocks
- A. Descriptive Classifications
- B. Physical Chemistry of the Minerals
- C. Magmas and Their Locales
- D. Rocks as Products of Defined Processes

Part IV. Metamorphic Rocks

Reserve your approval copy now

Ready in January, 1952 *Approx. 369 pages* *Prob. $7.00*

JOHN WILEY & SONS, Inc.

440 Fourth Avenue **New York 16, N.Y.**

Please mention the *Journal of Sedimentary Petrology* when writing to advertisers.

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

SOCIETY OFFICERS (APRIL 1951-MARCH 1952)

President: THOMAS H. PHILPOTT, Shreveport, Louisiana

First Past-President: WILLIAM C. KRUMBEIN, Evanston, Illinois

Second Past-President: H. B. STENZEL, Austin, Texas

Vice-President: KENNETH O. EMERY, Los Angeles, California

Secretary-Treasurer: CECIL G. LALICKER, Dept. of Geology, University of Kansas, Lawrence, Kansas

Editor: J. L. HOUGH, University of Illinois, Urbana, Illinois

PACIFIC SECTION OFFICERS (1950–1951)

President: LOUIS J. SIMON, Los Angeles, California

Secretary-Treasurer: DOUGLAS CRAWFORD, Compton, California

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

ASSOCIATION OFFICERS (APRIL 1951-MARCH 1952)

President: FRANK A. MORGAN, Los Angeles, California

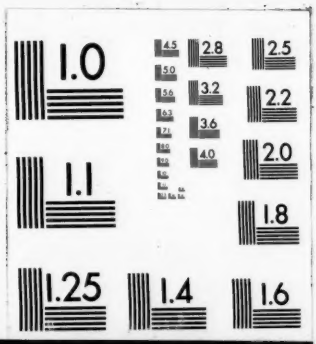
Past-President: C. L. MOODY, Shreveport, Louisiana

Vice-President: L. G. Weeks, New York, New York

Secretary-Treasurer: ROBERT H. DOTT, Oklahoma Geological Survey, Norman, Oklahoma

Editor: KENNETH K. LANDES, Ann Arbor, Michigan

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN


1.0
1.1
1.25
1.4
1.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.8